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INVESTIGATION OF DC-8 NACELLE MODIFICATIONS TO REDUCE FAN-COMPRESSOR NOISE IN AIRPORT COMMUNITIES

Part V - Economic Implications of Retrofit

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16. Abstract

The economic effects of retrofitting the airplanes with modified nacelles were studied for an assumed fleet of DC-8-50/61 airplanes in passenger service. These airplanes are equipped with nacelles having short fan-exhaust ducts. Estimates were made of the initial costs of retrofitting the airplanes with modified nacelles, and of the effects of the modifications on direct operating cost, profit, taxes, airplane investment, and return on airplane investment. In addition, estimated effects of the modifications on basic airplane performance characteristics were considered. These calculated performance characteristics (and the calculations of direct operating cost) were based on flight test results obtained in the third phase of the program. An economic life of 5 years was assumed for the retrofit kits on series 50 airplanes and 5 and 10 years on model 61 airplanes.

The study indicated that direct operating cost would be increased between 4 and 5 percent, assuming a 5-year amortization of the retrofit cost and modification of all short-duct DC-8 airplanes. Doubling the amortization period would approximately halve the increase in direct operating cost. The increase in direct operating cost would be due almost entirely to amortization of the costs of modification. On the assumption that operating revenues would be the same for the existing and treated airplanes, calculations indicated that profit after taxes and federal income taxes would be reduced about 10 percent for 5 years, the investment book value of airplane inventory would be increased 18.5 percent, and the discounted cash flow rate of return on airplane investment would be reduced about 8 percentage points, about a one-quarter reduction from the existing level.

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SUMMARY

In May 1967, the NASA initiated a program with the McDonnell Douglas Corporation to investigate turbofan-engine nacelle modifications designed to reduce fan-compressor noise from the JT3D engines on DC-8-50/61 aircraft. The program was directed at the definition of nacelle modifications that could reduce the perceived noise level by 7 to 10 PNdB under the landing-approach path, but with no increase in takeoff noise. The program was conducted in five phases: (1) nacelle design studies and duct-lining investigations, (2) ground static tests of noise suppressor configurations, (3) flyover-noise and cruise-performance tests of a selected modification design, (4) studies of the economic implications of retrofit of the modification, and (5) an evaluation of human response to the flyover noise of the modified nacelles. This document presents the results of the economic studies performed in phase 4 of the program.

The economic effects of retrofitting the airplanes with modified nacelles were studied for an assumed fleet of DC-8-50/61 airplanes in passenger service. These airplanes are equipped with nacelles having short fan-exhaust ducts. Estimates were made of the initial costs of retrofitting the airplanes with modified nacelles, and of the effects of the modifications on direct operating cost, profit, taxes, airplane investment, and return on airplane investment. In addition, estimated effects of the modifications on basic airplane performance characteristics were considered. These calculated performance characteristics (and the calculations of direct operating cost) were based on flight test results obtained in the third phase of the program. An economic life of 5 years was assumed for the retrofit kits on series 50 airplanes and 5 and 10 years on model 61 airplanes.

The study indicated that direct operating cost would be increased between 4 and 5 percent, assuming a 5-year amortization of the retrofit cost and modification of all short-duct DC-8 airplanes. Doubling the amortization period would approximately halve the increase in direct operating cost. The increase in direct operating cost would be due almost entirely to amortization of the costs of modification. On the assumption that operating revenues would be the same for the existing and treated airplanes, calculations indicated that profit after taxes and federal income taxes would be reduced about 10 percent for 5 years, the investment book value of airplane inventory would be increased 18.5 percent, and the discounted cash flow rate of return on airplane investment would be reduced about 8 percentage points, about a one-quarter reduction from the existing level.

INTRODUCTION

The total human annoyance from operations of commercial jet transports has increased simultaneously with the growth of the air transportation industry and the number of people living in communities around airports. This increased annoyance has stimulated efforts to find means to alleviate the problem through reducing the level of the noise radiated from the airplanes, modifying airplane operational procedures, and achieving compatible usage of the land around airports. The alleviation efforts have been conducted as part of a coordinated industry-government research program.

In May 1967, the Langley Research Center of the NASA contracted with the McDonnell Douglas Corporation and The Boeing Company to investigate nacelle modifications for operational McDonnell Douglas and Boeing transports powered by four Pratt & Whitney JT3D turbofan engines. The nacelle modifications were to achieve significant reductions in flyover noise levels in airport communities.

During landing approach, the perceived noisiness and hence the annoyance of the sound from the JT3D engines is attributed principally to the discrete frequency tones radiated from the fan stages through the inlet and fan-exhaust ducts. Accordingly, the purpose of the McDonnell Douglas and the Boeing investigations was to develop methods of suppressing fan noise. The McDonnell Douglas investigation was directed toward the determination of nacelle modifications that could suppress fan noise primarily through the use of fan-inlet ducts and short fan-exhaust ducts containing acoustically absorptive materials. A secondary noise-reduction concept to be investigated was that of reducing the fan rotational speed for a given landing thrust by controlling the area of the primary exhaust nozzle. The modifications were to be applicable to those DC-8 airplanes equipped with short-duct nacelles, that is, to the series 50 and the model 61 airplanes. The McDonnell Douglas goal was a 7 to 10 PNdB reduction in the outdoor perceived noise level under the landing-approach path. The Boeing goal was 15 PNdB. Both programs required that the nacelle modifications be designed to satisfy the following constraints:

- No adverse effect on takeoff or climbout noise.
- No compromise with flight safety.
- No additional flight-crew workload.
- Retroactively modified airplanes to be economically viable.

In seeking economic viability, efforts were to be made to minimize the changes required to existing nacelle or pylon structure and equipment.

The McDonnell Douglas program was performed, and is reported, in five phases: (1) initial nacelle-modification design studies and duct-lining investigations (ref. 1); (2) ground static tests of suppressor configurations (ref. 2); (3) a flight investigation of the acoustical and performance effects of the selected design of modified nacelles on a DC-8-55 airplane (ref. 3); (4) a study of economic implications of retrofit of the selected design (this document); and (5) an evaluation of human response to the flyover noise of the modified nacelles (ref. 4). Reference 5 provides a summary of the McDonnell Douglas program results. The results of the Boeing program are reported in reference 6.

In this document are examined the economic implications of retrofitting a fleet of DC-8 series 50 and model 61 airplanes with acoustically treated nacelles. These airplanes constitute about 50 percent of the total DC-8 fleet.

Studies were made of (1) a program schedule for a fleet retrofit, (2) the initial costs of retrofitting the airplanes, (3) the changes in direct operating costs due to the modifications, and (4) the effects of retrofitted airplane and fleet operations on cash-flow criteria, airplane investment, and return on airplane investment. In order to perform these studies, it was necessary to make a number of assumptions regarding basic factors that are uncertain at this time. As these factors become better defined, each interested organization should assess the assumptions of this study and make such further analyses as may be appropriate.

METHODOLOGY

Basic Approach

The basic approach of this study was to identify and measure the primary economic effects of the retrofit modification. The primary effects are defined as those that would appear if the existing airplanes were replaced in service by the modified airplanes without change in annual utilization, revenue passenger miles, route system, or retirement and replacement date. Both the existing and the modified airplanes were measured against the same operational task, and their cash flow levels were calculated. The differences in their cash flow levels were, therefore, measures of the primary effects of the modification, since no other input changes were allowed.

Steps in the economic analysis, described more fully in the succeeding sections, included:

- Airplane performance calculations: Identification and definition of airplane performance changes resulting from the retrofit.

- Retrofit cost estimate: Estimation of the initial cost of the retrofit, which included design definition, program definition, and scheduling, to encompass development, certification, kit production, and retrofit installation on an operational fleet of DC-8 airplanes.

- Direct operating cost (DOC) calculations: Calculation of the effects the performance changes and total retrofit costs would have on airplane direct operating costs.

- Economic assessment: Estimation of the effects, on each short-duct DC-8 model and on total fleet operations, of the changes in operational economics caused by the foregoing changes in airplane performance, capital investment, and operating costs.

Airplane Performance Calculations

Airplane performance calculations with respect to range for the existing and modified airplanes were made to determine the effects of the retrofit on payload-range, FAA takeoff field length, and initial cruise altitude capability. Performance was calculated for the existing and treated DC-8-51, DC-8-52, DC-8-53, DC-8-54, DC-8-55, and DC-8-61.

The performance for the existing airplanes was based on flight test data. The performance data for the modified airplanes was determined by applying to the performance of the existing models the performance changes due to the modification indicated by the flight test program of reference 3. A discussion of the methods of performance calculation is presented in reference 3.

Retrofit Price Estimation

The cost of the airplane retrofit kit, installed, was estimated in the same way that a competitive cost quotation would be prepared: (1) The design was defined to a level of detail that permitted the significant tasks and nacelle components to be identified and described in terms sufficient to permit a cost analysis. (2) A retrofit program plan was defined encompassing engineering development, tooling, manufacturing, kit delivery rates, retrofit installation, and spare parts stockpiling. (3) Retrofit kit costs were estimated by item and aggregated on the basis of the foregoing design and program definitions. The cost estimates were then increased by 4 percent per year to raise them to expected 1972 levels.

Design definition. – Figure 1 presents comparative sketches of the existing and treated JT3D nacelles to illustrate the principal modifications that were made. One concentric ring-vane was added to the inlet, the fan-exhaust ducts were lengthened from 24 to 48 inches, acoustical treatment was applied to inlet and exhaust surfaces as indicated, and new fan-exhaust thrust reversers were necessitated by the lengthening of the fan-exhaust ducts.

The scope of the modification is indicated in terms of weight of items removed and added in the weight change summary of table I. A more comprehensive definition and discussion of the acoustically treated nacelle design is presented in reference 3.

Program definition. – Program definition started with an estimate of the number of short-duct DC-8 airplanes that might be candidates for retrofit. As of 31 August 1969, there were 228 short-duct DC-8 airplanes in service. Additional short-duct DC-8 airplanes are to be produced, which will increase the number of airplane retrofit kits potentially required. However, two other factors would tend to reduce the number required. First, the older short-duct DC-8 airplanes may be near the ends of their economic lives at the time retrofit kits could be available. Second, foreign operators may be able to continue service with unmodified airplanes into airports where noise is not a problem. In view of these factors, it is believed that the maximum number of short-duct DC-8 airplanes that could be candidates for retrofit is on the order of 250. A 20 percent spares factor would add 50 kits, thus requiring the production of a total of 300 airplane kits.

Another step in program definition was the assumption of a program schedule. The assumed retrofit program schedule is outlined in figure 2. A 5-year overall program was assumed. The 5-year program shown would provide for retrofit installation of the modified nacelles on airplanes during scheduled engine or airplane overhauls and, thus, would require no out-of-service time for installation. The first 2 years of the program are necessary for development, tooling, and certification. The third through the fifth years of the program encompass retrofit kit production and installation. Both the McDonnell Douglas and the Boeing studies were scheduled to be completed in late 1969; therefore 1 January 1970 was assumed to be the earliest practicable start date for a production program, and 1 January 1972 would be the earliest practicable date to begin installation of the kits.

The program plan was constructed around four principal phases; engineering development, production tooling and kit manufacturing, retrofit installation of the kits on the airplanes, and spares stockpiling. Engineering development preceded the other three phases, although with a period of overlap. The last three phases were essentially concurrent, but with their start dates sufficiently staggered to maintain a reasonable supply of retrofit kits on hand before installation was begun.

Cost estimates. – Based on the retrofit nacelle design definition, engineering development costs were estimated as follows. Each affected engineering group prepared estimates of the manhours, materials, and special facilities needed to perform its part of the tasks. These estimates were aggregated and increased by the appropriate overhead and support burden factors and by other major identifiable development costs such as laboratory support, flight tests through certification, and computing machine time.

Manufacturing estimates were made of manhours and materials requirements, based on experience with similar production operations on the DC-8 production lines. Production planning and tooling costs were estimated commensurate with the scheduled production rate of 100 airplane retrofit kits per year. Manufacturing overhead and support burden increments were calculated and added on the basis of DC-8 production experience factors.

The cost of installing the modified nacelles as a retrofit to existing airplanes was held to a minimum by performing the installation during the routine scheduled airplane overhaul. Airplane overhaul is performed on approximately a 3-year cycle, and involves approximately a week out of service for the airplane. During this week, the nacelle retrofit could be accomplished with no extra airplane downtime.

The foregoing steps resulted in cost estimates at 1968 levels. An assumption for this study was that costs and prices of labor, materials, and facilities will continue to increase at a rate of 4 percent per year compounded. With the retrofitting of airplanes scheduled to begin in 1972, the cost estimates were escalated to 1972 levels. This was done by increasing the cost estimates at the assumed escalation rate of 4 percent per year compounded from 1968 base levels to 1972 levels.

Direct Operating Cost Calculations

Direct operating costs were calculated using an adaptation of the standard 1967 Air Transport Association of America (ATA) method (ref. 7). The elements of DOC are defined in table II. The sum of the elements is the total direct operating cost. For the existing airplane, DOC was computed as shown in table II. For the modified airplane, the depreciation and maintenance elements were computed differently:

- Depreciation: Additional terms were calculated and added to the three depreciation elements of table II. The additional terms accounted for the added depreciation of the retrofit kits and spares amortized over the depreciation periods assumed for the retrofit kits.

- Maintenance: Table II expresses nacelle maintenance costs as simple functions of engine thrust and cost. For the purposes of the study, the incremental maintenance due to the modified nacelles was estimated by analysis of the changes in maintenance tasks and materials.

The assumptions used for the DOC calculations are listed in table III. Several of the assumptions reflect adjustments of the standard ATA method and input values to satisfy the particular requirements of this study. The standard depreciation period of 12 years was used for the airplane, but the added cost of the nacelle modification was depreciated over a 5 (or 10) year period. This implies the assumption that the airplane would be retrofitted at the end of its seventh (or second) year of service, and that depreciation of the additional investment in the retrofit nacelles would then be concurrent with the last 5 (or 10) years of airplane service life and depreciation. Fixed utilization of 3800 hours per year was used rather than the variable ATA values. Standard spares factors of 10 and 40 percent, respectively, were used for airframe and engines, and a 20 percent spares factor was introduced for the nacelle parts to correspond with spares practice on quick-engine-change components. Zero downtime was assumed for retrofit-kit installation, in the expectation that installation could be phased with normally scheduled downtime for maintenance. The installed price of the retrofit modification was $546 000 per airplane, without spares. The price of the existing airplane would be increased by the price of the retrofit kit installed.

Economic Assessment

The economic effects of the retrofit were studied for the model 55 that was test-flown, for the other short-duct DC-8 models, and for the estimated 1972 fleet of short-duct DC-8 airplanes. The changes in operating economics due to the airplane performance changes, retrofit costs, and changes in DOC were estimated and evaluated. The 5 years 1972 through 1976 were selected as the time period for the economic assessments.

DC-8-55 airplane. – To evaluate the economic aspects of the retrofit, comparisons were made between the existing and modified airplanes as though each were operating under the same average service conditions. Preliminary studies demonstrated that cash flow calculations based on an average range of 850 nautical miles resulted in average operating revenues, costs, and profits, and in valid economic comparisons between the two airplanes. Particular assumptions used in the economic analysis are listed in table IV.

The revenue-earning capability of the airplane with modified nacelles was assumed to be the same as that of the existing unmodified airplane. Not evaluated were the increased payload-range capability or the possibilities of earlier retirement, changes in route structure, and changes in airplane task assignment. Revenue calculations were based on published air fares as of May 1969. Although it is recognized that fares might be increased to accommodate the increased operating costs of the modified airplane, this factor was not treated in the study.

Both airplanes were in passenger service, both operated at a 50-percent load factor, and both had the same indirect operating costs (IOC), calculated at 42 percent of revenue. The cost of the retrofit was treated as an increase in capital investment rather than as an expense. The same 48-percent corporate income tax rate was applied to the operations of both airplanes, and the investment tax credit was treated as zero in calculating each airplane's cash flow status.

DC-8 short-duct fleet. – The method discussed in the preceding section dealt with only one of the 6 short-duct DC-8 models. The same method was used in a similar analysis that was performed on each of the other 5 models. The results for the 6 models were combined to evaluate the effect of the total fleet retrofit. The estimated composition of the short-duct DC-8 fleet at the start of 1972 is as follows:

DC-8 Model	Quantity
–51	34
–52	27
–53	27
–54	28
–55	33
–61	101
Total	250

The model 61 is the only short-duct DC-8 airplane presently in production, and deliveries by the start of 1972 may differ from the estimate of 101 shown. Attrition and retirement are additional unpredictable factors that make the total of 250 airplanes a working estimate only.

Procedure. – Based upon the estimated retrofit costs, changes in airplane performance, and changes in direct operating costs due to the retrofit, the following studies were performed:

- Calculation of the per-airplane operating economics of each model serving its representative traffic for 5 years, and of the model 61 for 5 and 10 years. In the example shown in table VI, the annual revenue passenger traffic carried by the DC-8-55 at the block distance of 850 n. mi. is 103 000 000 revenue passenger miles (RPM), the product of utilization x speed x seats x load factor: 3800 x 402 x 135 x 0.50 = 103 000 000. Under the assumptions of this study, block speed is the only one of the foregoing variables that is range-sensitive. Traffic calculated at the average range of 850 n. mi. resulted in RPM values that are very close to reported average annual RPM for DC-8 airplanes.

- Comparison of each existing and modified model by the following criteria:

  - Annual cash flow items:

    Operating revenue

    Operating expenses (less depreciation)

    Depreciation

    Pre-tax profit

Income tax

After-tax profit

Cash flow

- Airplane investment

- Return on airplane investment.

- Aggregation of the foregoing data and comparisons by total fleet for the 5 years, 1972 through 1976.

ROI program. – The Return on Airplane Investment Program is a digital computer program used to facilitate the calculations described in the preceding paragraphs. Return on airplane investment as calculated in the ROI Program refers only to the return derived from airplane operations and the investment in the airplanes. It therefore does not include return derived from other business operations or investments other than for airplanes.

Inputs. – Table V summarizes and defines the inputs used for the return on airplane investment evaluations of this study. Most of the items involve standard elements that need no explanation. The treatment of block distance and yield are discussed below.

Block distance. – In the ROI Program, block distance is an independent input variable. Because speed, utilization, DOC, IOC, and yield may vary with range, each is to a degree dependent upon the block distance selected. Nevertheless, as previously noted under the assumptions of this study, utilization was held fixed at 3800 hours per year, and IOC was treated as a function of revenue. Trial calculations at various block distances led to selection of 850 n. mi. for the economic comparisons of this study because results at that range correlated well with reported data on average DC-8 annual revenues, expenses, and profits.

Yield. – First-class (F) and economy (Y) fares for selected markets were abstracted from reference 8. The passenger ratio of first-class travel by trip distance was determined by examining the "Summary by Length of Passenger Trip" report found in reference 9. The passenger (Pax) ratio of first-class service by 50-mile increments was taken as: Pax Ratio = Number of Pax using coach service/Number of Pax traveling. The Pax ratios were plotted versus range and a curve fitted to them. The following levels of yield dilution factors were assumed; F, 10 percent, and Y, 20 percent.

Using the above information, a weighted average diluted fare for each selected market was calculated using the equation:

$$\text{Weighted Fare} = 0.90 \begin{pmatrix} \text{Pax Ratio} \\ \text{for 1st class} \\ \text{service expressed} \\ \text{as a decimal} \end{pmatrix} \begin{pmatrix} \text{First} \\ \text{Class} \\ \text{Fare} \end{pmatrix} + 0.80 \begin{pmatrix} \text{Pax Ratio} \\ \text{for coach} \\ \text{service expressed} \\ \text{as a decimal} \end{pmatrix} \begin{pmatrix} \text{Coach} \\ \text{Fare} \end{pmatrix} \qquad (1)$$

Where

Pax ratio for 1st class service	+	Pax ratio for coach service	= 1

A least-squares line was then fitted to the weighted average fares to give the fare defining equation as:

(i) $\text{Fare} = A + B \times (\text{Distance})$

where $A = \$11.010800$ and $B = \$0.042798$

When distance is expressed as statute miles.

(2)

and where $A = \$11.010800$ and $B = \$0.049286$

When distance is expressed as nautical miles.

The yield defining equation is then:

(ii) $\text{Yield} = B + A/\text{Distance}$ (3)

Figure 3 is the curve calculated from these equations and the foregoing coefficients for yield per nautical mile, U.S. domestic data. The value A may be considered as a fixed "dollars to board" the airplane, and B a constant "dollars per revenue passenger mile."

The foregoing curves represent the general U.S. domestic fare and yield versus distance relationships. The ratio of first class travel to total travel rises rapidly as distances decrease. A specific airplane such as the DC-8, which typically offers an approximate 20/80 percent mix of first class/coach accommodations, cannot carry more than its capacity of first class, regardless of the general curves. The general yield versus distance curves were therefore adjusted for the DC-8 study to hold the first class ratio constant once the airplane's first-class capacity had been reached.

Outputs. – Table VI illustrates a typical output printout sheet from the ROI Program. Most of the input values are listed for reference on the top half of the sheet. The bottom half of the sheet lists the annual cash flow values computed from these inputs, ending with the overall ROI calculated as the discounted cash flow rate of return on average airplane investment over the 5 (or 10) year economic life of the retrofit investment.

Cash flow is the sum of post-tax profit and depreciation. Depreciation is handled separately from the other elements of operating costs. Total direct plus indirect operating cost is the sum of cash costs and depreciation. The separation of depreciation is to make visible the effect of amortization policy on total costs and economic performance of the airplane.

RESULTS AND DISCUSSION

Airplane Performance Changes

The ground and flight tests discussed in reference 3 defined the changes in two basic performance characteristics due to the nacelle modification, namely, the changes in the installed engine thrust ratings and airplane cruise specific range.

Analysis of the ground test data indicated that the rated takeoff, maximum continuous, and maximum cruise thrusts were reduced by 2.5, 2.9, and 3.1 percent, respectively (ref. 3). These thrust reductions were offset to some extent by the reduction in the drag due to the fan exhaust flow scrubbing the nacelle afterbody. It is estimated that the longer fan exhaust ducts reduced the scrubbing drag approximately 0.4 percent. Since installed net thrust as defined for airplane performance calculations includes scrubbing drag as a thrust loss, the reductions in installed net takeoff, maximum continuous, and maximum cruise thrusts were 2.1, 2.5, and 2.7 percent, respectively. Analysis of the flight test data indicated that the cruise specific range was improved an average of 3 percent over the range of normal cruise operating weights.

It is believed that the aerodynamic flow in the region of the nacelle and pylon was improved by the more downstream location (24 inches) of the fan exhaust nozzles, and that the resultant improvement in drag was more than sufficient to offset the increased internal total-pressure losses of the modified nacelle.

The operating empty weight of the airplane was estimated to increase by 332 pounds due to a retrofit installation of a production version of the modified nacelle (table I). Nacelle components totalling 5156 pounds per airplane would be removed and replaced by new or reworked components totalling 5488 pounds per airplane. The principal elements of weight change consisted of 1480 pounds per airplane of weight added by acoustically treated inlet and fan exhaust ducts, and 1148 pounds per airplane of weight reduced due to the lighter weight of the new fan thrust reversers.

The basic changes in installed engine thrust ratings and airplane cruise specific range, together with the weight change, were used in the calculation of the airplane performance changes discussed in the following paragraphs.

Block speed. – Climb performance of the DC-8 airplane would not be affected significantly by the nacelle modification. The airplane drag reduction implied by the improved cruise performance is believed to apply at Mach numbers above approximately 0.6, which occur during the latter portion of the climb. Climb performance during this portion of the climb, where the majority of the climb time is spent, would not be appreciably affected by the modification since the drag reduction is approximately equal to the reduction in climb thrust, which is equal to rated maximum continuous thrust for the JT3D-3B engine. At low altitudes and speeds, where the drag advantage may not be present, the thrust minus drag margin and, hence, the rate of climb, is high. Small drag differences during this part of the climb would have a negligible effect on the total time to climb. Further, the reduction in maximum cruise rated thrust would not preclude operating the airplane at Mach numbers currently used for either long range or high speed (Mach 0.82) cruise. Therefore, no change in block speed would result from the modification.

Payload-range. – The effects of the modified nacelles on airplane payload-range characteristics are shown in figures 4 and 5. For each airplane model, the payload-range curves, with and without the modified nacelles, are presented both for domestic and international operation. The reference payload is defined as a full passenger payload (at 205 pounds per passenger and his baggage) plus 2500 pounds of cargo. The payload-range curves are for long-range cruise, and apply for operations with runways sufficiently long to accommodate takeoffs at maximum certified takeoff weights.

Initial cruise altitude. – No test data were obtained to directly evaluate maximum initial cruise altitude. However, some estimates were made on the basis of the cruise test data that most nearly approached this condition. The maximum initial cruise altitude of the DC-8-55 for all actual gross weights occurs at a W/δ (referred gross weight) of 1 100 000 lb. The cruise data at this W/δ and 0.82 Mach number indicated an apparent drag reduction of 1.2 percent. This reduction in drag is more than offset by the 3.1 percent loss in maximum cruise thrust due to the reduction in the rated maximum cruise engine pressure ratio. The resultant loss of 1.9 percent in thrust minus drag margin is estimated to produce a 500-foot decrement in maximum initial cruise altitude. This decrement would not affect range capability at long-range cruise, and would result in less than a 5-mile range reduction at 0.82 Mach cruise. The effect on the other DC-8 models would be expected to be similar.

Takeoff field length. – The takeoff field length characteristics of each existing and modified short-duct DC-8 model are illustrated in figure 6. In all cases, the modified airplane requires greater takeoff field lengths at ranges less than approximately 2500 n. mi., reflecting the dominance of the reduced rated takeoff thrust, and it requires shorter takeoff field lengths at ranges more than approximately 2500 n. mi., reflecting the dominance of the improvement in cruise fuel consumption and resulting lighter fuel load.

The flat tops of all the takeoff field length curves correspond to the maximum certified takeoff weight of the airplane. The horizontal distance spanned by the flat top of each curve corresponds to the increased range that would be achieved, with the same payload and fuel load, as airplane cruise speed for the trip is reduced from high speed cruise of Mach 0.82 to the lower speeds of long range cruise. The cutoff point of each curve is the maximum range capability with the reference payload.

The takeoff rated thrust reduction of 2.1 percent for an airplane equipped with modified nacelles would result in a decrease in second-segment limiting weights of 2.1 percent (ref. 3). Under the conditions of sea level takeoff and ambient temperatures up to 84°F, the modification would result in second-segment limiting weights that were slightly less than the maximum takeoff gross weights of the two heaviest models, 55 and 61. For each model, the loss in second-segment limiting weight would be about 6000 pounds. This would require that the takeoff flap setting be reduced from 25° to 15° for weights near maximum takeoff weight, and the required field length consequently would be increased. The increases in field length requirement for the models 55 and 61 are shown in the required takeoff field length curves of figures 6(e) and 6(f) as the vertical dotted portions of the curves for the modified airplanes. The airplane field length requirements with existing nacelles are not affected by the second-segment weight limitation at temperatures up to 84°F. The models 51, 52, 53, and 54 have smaller maximum takeoff gross weights than the models 55 and 61, and would reach their maximum takeoff gross weights before reaching their second-segment limiting weights under the same conditions of sea level takeoff and ambient temperatures up to 84°F.

In all cases of operations at maximum range, more takeoff field length is required by the modified airplanes.

Retrofit Price Estimate

About 250 short-duct DC-8 airplanes are expected to be in service in the early 1970s. Retrofit prices were estimated on the basis of 300 airplane kits to be produced in the years 1972 through 1974, which assumes retrofit of the total 250 airplanes and includes a 20-percent allowance for spares. The elements of the price estimate were as follows:

Retrofit price element	Price (1972 dollars)
Development	$ 52 000
Tooling	11 000
Manufacturing	480 000
Installation	3 000
Subtotal (per airplane kit)	$546 000
Spares (20 percent)	109 000
Total (per airplane)	$655 000

The estimated 1972 values would have to be adjusted if the number of kits, the time period, or the escalation factor differed from assumptions that were used.

Development and tooling represent estimated nonrecurring or fixed costs, whereas manufacturing represents the estimated recurring or variable per-kit cost of production at the 300-unit level of production. The total price per kit installed was estimated to be $546 000. With 20 percent spares, the total price per airplane would be $655 000.

Figure 7 illustrates the variation of kit unit price with the number of airplane kits to be produced. The larger the base over which the nonrecurring costs are allocated, the lower the per-unit price of the airplane kit. The curve also reflects some economies of scale and improvements in production efficiency with quantity.

Direct Operating Costs

The direct operating costs that were calculated for the existing and modified short-duct DC-8 airplanes are shown in figure 8 for domestic rules, and figure 9 for international rules. Both sets of figures reflect the assumption of a 5-year depreciation period of the modification. Figure 10 shows the DOC of the DC-8-61, existing and modified, using domestic and international rules, for a 10-year depreciation period of the modification.

Figure 11 shows the increase in DOC as a function of range for each of the short-duct DC-8 models. With the cost of the modification amortized over a 5-year period, the increases in DOC at 850 n. mi. ranged between 4 percent for the model 61 to about 5 percent for the model 51. The figure also shows that the increases in DOC are relatively flat through most of the normal operating ranges of each model, illustrating the relative insensitivity of these data to range.

With the cost of the modification amortized over a 10-year period, the increase in DOC of the model 61 was 2 percent, as shown by the lowest curve on figure 11. This is approximately half the increase in DOC that resulted from a 5-year depreciation period.

Table VII shows a sample, for two airplanes, of the elements that constitute the change in DOC shown in figures 8, 9, 10, and 11. The change in each element is shown as a percent of DOC. The example shown is for the 5-year depreciation period of the retrofit for the model 55, and 5- and 10-year depreciation periods for the model 61. Crew cost did not change, since block time was not perceptibly changed by the modification. The insurance increase reflects the increased book value of the airplane after the modification. The fuel cost decrease reflects the improved fuel consumption of the modified airplane.

Maintenance was estimated by task analysis to increase about $1.00 per flight hour, or about 0.1 percent of DOC. This preliminary estimate is subject to change when additional experience is accumulated on the service life, inspection and repair costs, and cleaning costs associated with the acoustic materials that would be used. The changes in insurance, maintenance, and fuel cost approximately cancel each other.

The change in depreciation, which is due to amortization of the added cost of the modification, was found to be the dominant element of the overall net change in DOC.

Economic Implications

The effects of the retrofit program on each model's operational economics, based on the assumptions and effects previously discussed, are summarized in table VIII. Each part of the table may be thought of as a representative economic summary for one airplane of the short-duct DC-8 model identified in the sub-legend. The first two columns show the computed values for the existing and the modified airplane, and the third column shows the differences. Where appropriate, the third column is split to show the difference as an amount and also as a percent of the existing unmodified value.

The differences in base values between the 6 existing airplane models are due mainly to differences in price, payload capacity, and takeoff gross weight. The retrofit did not affect the revenue-earning capability. This result followed from the ROI program inputs of the same utilization, number of seats, load factor, yield, and block speed for both the existing and modified airplanes. The operating-expenses-less-depreciation component of direct operating cost reflects amortization of the retrofit cost. The depreciation effect was so dominant that the aggregate effects of the other changes in operating costs were not perceptible.

Since the cost of the retrofit was the same for each airplane model, the amounts of the differences in the profits, taxes, and cash flow items were the same. Depreciation and investment increased the same amount, balanced by an equivalent decrease in profit before taxes. The effect of the assumed 48 percent corporate tax rate on profits was to shift 48 percent of the burden of paying for the retrofit to the Government, in the form of reduced income taxes from the airplane operator. The remaining 52 percent of the burden of paying for the retrofit remained with the operator in the form of reduced profit after taxes. Annual cash flow, which is the sum of depreciation and profit after taxes, increased since the increase in depreciation was greater than the decrease in profit after taxes.

The per-airplane investment was calculated to be the depreciated value of the airplane at the time of the retrofit, which was assumed to be at the end of the seventh year. Investment was increased in each case by $655 000, the cost of the retrofit plus spares.

The return on airplane investment is a discounted cash flow rate of return on the airplane investment over the economic life of the investment. The annual cash flow (comprising net profit after tax, plus any *initial investment* tax allowance, plus the annual depreciation allowance) is considered to accrue in twelve monthly cash streams. These cash streams, together with interest earned in the year at a rate equivalent to the discount rate, are consolidated into a year-end cash flow, which is then discounted back on a compounded basis to the year of the investment, resulting in a present value of a future cash flow. The discount rate at which the total present value of the summation of the cash flows just recoups the investment over its useful life is (in this method of economic evaluation) termed the discounted cash flow rate of return. As previously noted, the study method deals with airplane investment only. It does not include plant, facilities, and other items that customarily are included in an accounting of an airline's total investment.

Based on the foregoing per-airplane data, the 5-year economic impact on the composite mixed fleet of 250 short-duct DC-8 airplanes is summarized in table IX. The weighted average ROI for the modified fleet decreased 8.1 percentage points, approximately a one-quarter reduction from the existing level. Operational profit after taxes decreased by 10.2 percent or $85 000 000, while airplane investment increased by 18.5 percent or $164 000 000. The balance, $79 000 000, represented less income taxes paid by operators and less income taxes received by Government, 10.2 percent in each case.

CONCLUDING REMARKS

The preceding discussion has indicated some economic effects of retrofitting short-duct DC-8 airplanes (the DC-8 series 50 and model 61 airplanes) with acoustically treated nacelles. To retrofit 250 airplanes and provide 20 percent spares would require production of 300 airplane retrofit kits. The initial cost of retrofit, including spares, was estimated to be $655 000 per airplane in 1972.

Estimates were made of the airplane performance and investment changes due to the nacelle modifications, and of the resultant effect on direct operating costs. These estimates indicated that, with 5-year depreciation of the retrofit, average direct operating costs would be increased 4 to 5 percent, with the least adverse impact on the largest and most profitable model, the extended-fuselage DC-8-61. Doubling the depreciation period would approximately halve the increase in direct operating costs.

On the basis of the assumptions that the retrofit program would not affect revenues, scheduling, utilization, route and traffic assignment, or remaining economic life and retirement plans for the airplanes, it was estimated for the total short-duct DC-8 fleet that profits (and federal income taxes) would be reduced about 10 percent for 5 years, investment book value of airplane inventory would be increased 18.5 percent, and the discounted cash flow rate of return on airplane investment would be reduced about 8 percentage points, about a one-quarter reduction from the existing level.

The economic effects determined in this study apply only to DC-8 airplanes with short-duct nacelles. The total DC-8 fleet in 1972 is expected to include not only the 250 short-duct DC-8 airplanes discussed but also approximately an equal number of other DC-8 models, including turbojet engines and long-duct nacelle installations to which these study results do not apply.

The economic impact on individual operators and on the industry of retrofitting existing airplanes with acoustically treated nacelles warrants further study in which consideration can be given to factors such as fleet reequipment plans and possible changes in airplane traffic and route assignments, fares, and future local, federal, and international noise regulations.

Douglas Aircraft Company
McDonnell Douglas Corporation
Long Beach, California October 1969

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TABLE I. – SUMMARY OF WEIGHT CHANGES

Item	Weights per nacelle, lb		Change in weight, lb		Notes
	Out	In	Per nacelle	Per airplane	
Inlet duct	230	230	0	0	N
Treatment – cowl . . .	–	61	+61	+244	N
Treatment – ring-vane. .	–	75	+75	+300	N
Nose bullet	14	17	+3	+12	N
Treatment – bullet . . .	–	7	+7	+28	N
Fan exhaust duct . . .	98	200	+102	+408	N
Treatment – duct . . .	–	122	+122	+488	N
Fan exhaust reverser . .	475	188	–287	–1148	N
Pneumatic ducting inlet . .	37	37	0	0	N
Access doors:					
Left-hand doors	138	138	0	0	N
Right-hand doors	145	145	0	0	N
Interstage bleed duct . . .	12	12	0	0	N
Engine power controls . .	18	18	0	0	N
Anti-ice valves and lines . .	50	50	0	0	N
Generator cooling duct . .	5	5	0	0	N
Hydraulic plumbing	22	22	0	0	N
Ventilation duct	5	5	0	0	S
Oil system plumbing . . .	16	16	0	0	N
Pneumatic ducting (center section)	24	24	0	0	S
Total	1289	1372	+83	+332	

N = New
S = Similar

TABLE II. – DEFINITION OF DIRECT OPERATING COST ELEMENTS

Element	Definition
• Flying operations in dollars per nautical mile:	
Crew	$= \dfrac{(\text{Max TOGW}^{a} \times 5 \times 10^{-5} + 135 + (20)^{b})\ \text{block time}}{\text{Range}}$
Oil	$= \dfrac{1.25 \times 10^{-1} \times \text{No. engines} \times \text{block time}}{\text{Range}}$
Hull insurance	$= \dfrac{\text{Aircraft total cost} \times \text{insurance rate} \times \text{block time}}{\text{Annual utilization} \times \text{range}}$
Fuel	$= \dfrac{\text{Lb of fuel burned} \times \text{cost of fuel/lb}}{\text{Range}}$
• Depreciation in dollars per nautical mile:	
Complete aircraft	$= \dfrac{\text{Aircraft total cost} \times \text{block time}}{\text{Annual utilization} \times \text{airframe depreciation period} \times \text{range}}$
Airframe spares	$= \dfrac{\text{Spares rate} \times \text{airframe cost} \times \text{block time}}{\text{Annual utilization} \times \text{airframe depreciation period} \times \text{range}}$
Engine spares	$= \dfrac{\text{Spares rate} \times \text{No. engines} \times \text{engine price} \times \text{block time}}{\text{Annual utilization} \times \text{airframe depreciation period} \times \text{range}}$

a TOGW – Takeoff gross weight, lb
b Increment for international operation

TABLE II. – DEFINITION OF DIRECT OPERATING COST ELEMENTS – Concluded

Element	Definition
• Cyclic maintenance in dollars per nautical mile:	
Labor, airframe	$= \dfrac{5\left(\text{Airframe Wt}^{a}\,\dfrac{0.05}{1000} + 6 - \dfrac{630}{120 + \dfrac{\text{Airframe Wt}}{1000}}\right)}{\text{Range}}$
Labor, engines	$= \dfrac{\text{No. engines } (1.5 + \text{Max TO thrust}^{b} \times 1.5 \times 10^{-4})}{\text{Range}}$
Material, airframe	$= \dfrac{\text{Cost of airframe} \times 6.24 \times 10^{-6}}{\text{Range}}$
Material, engines	$= \dfrac{\text{No. engines} \times 300\,000 \times 2 \times 10^{-5}}{\text{Range}}$
Burden	= 1.8 (labor airframe + labor engines)
• Hourly maintenance in dollars per nautical mile:	
Labor, airframe	$= \dfrac{2.95\left(\text{Airframe Wt}\,\dfrac{0.05}{1000} + 6 - \dfrac{630}{120 + \dfrac{\text{Airframe Wt}}{1000}}\right)\left(\begin{matrix}\text{flight}\\ \text{time}\end{matrix}\right)}{\text{Range}}$
Labor, engines	$= \dfrac{\left(\text{No. engines}\right)\left(3.00 + \text{Max TO thrust} \times 1.35 \times 10^{-4}\right)\left(\begin{matrix}\text{flight}\\ \text{time}\end{matrix}\right)}{\text{Range}}$
Material, airframe	$= \dfrac{\left(\text{Cost of airframe}\right)\left(3.08 \times 10^{-6}\right)\left(\text{flight time}\right)}{\text{Range}}$
Material, engines	$= \dfrac{\left(\text{No. engines}\right)\left(300\,000\,(2.5 \times 10^{-5})\right)\left(\text{flight time}\right)}{\text{Range}}$
Burden	= 1.8 (labor airframe + labor engines)

a Wt – Weight, lb
b Max TO thrust – Maximum takeoff thrust, lb

TABLE III. - ASSUMPTIONS FOR DIRECT OPERATING COST CALCULATIONS

Item	Assumption
Wind:	Zero
Temperature:	Standard atmosphere (climb-cruise); 84°F (takeoff)
Pressure:	Standard atmosphere
Altitude:	Sea level takeoffs and landings
Cruise procedure:	Step cruise at 30 000, 35 000, and 40 000 feet
Depreciation:	Existing aircraft – 12 years, straight line Retrofit kit – 5 years, straight line; except DC-8-61, 5 years and 10 years
Utilization:	3800 hours per year
Spares factors:	Airframe 10% Retrofit kit 20% Engines 40%
Downtime for retrofit: . . .	None
Increment in maintenance cost due to retrofit nacelles:	Established by task analysis
Cost of kit installed:	$546 000 (1972 dollars based on 1968 values escalated at 4% per year compounded.)
Seats per aircraft:	Representative values of current service, as follows: DC-8-51 – 124 seats; DC-8-54 – 135 seats DC-8-52 – 124 seats; DC-8-55 – 135 seats DC-8-53 – 129 seats; DC-8-61 – 198 seats
Operation:	International and domestic
Crew:	Three-man
Fuel:	International, 11 ¢/gal. Domestic, 10 ¢/gal. (Fuel density taken as 6.7 lb/gal.)

TABLE III. – ASSUMPTIONS FOR DIRECT OPERATING COST CALCULATIONS – Concluded

Item	Assumption
Reserves, international: . . .	Fuel to fly 10% of block time at final cruise altitude at 99% maximum miles per pound, plus Fuel to fly 200 nautical miles to an alternate airport and hold one-half hour at 1500 feet altitude.
Reserves, domestic:	Fuel to fly one hour at 99% maximum miles per pound at final cruise weight and best altitude, plus Fuel for missed approach (two minutes at takeoff thrust), plus Fuel to climb, cruise and descend a total distance of 200 nautical miles (cruise at least half the distance).
Insurance rate:	2% of initial (and added) airplane value.
Ground maneuver time per flight:	0.25 hour
Cost of JT3D engines: . . .	$300 000 per engine
Labor cost:	$5.00 per hour in 1972
Residual value of aircraft and retrofit kit:	Zero

TABLE IV. – ASSUMPTIONS FOR ECONOMIC ANALYSIS

Item	Assumption
All DOC assumptions (table III), plus:	
Yield:	Variable with range, based upon fare structure (fig. 3).
Load factor:	0.50
Indirect operating cost (IOC): .	42% of gross revenue at number of seats, load factor, yield, and utilization of the particular aircraft model and range.
Basic constraints on analysis: .	Passenger service only. DC-8 with short duct pods only.
Financial treatment of retrofit:	Investment (rather than expense).

TABLE V. – DEFINITIONS OF INPUTS FOR ROI PROGRAM

Item	Input
Block distance	Range in nautical miles (n. mi.) (850 n. mi. for this study)
Block speed	Block speed in knots
Daily utilization	10.4 hours per day
Operating factor	365 (This factor x daily utilization = annual utilization)
Seats per aircraft	DC-8-51 – 124 DC-8-54 – 135 DC-8-52 – 124 DC-8-55 – 135 DC-8-53 – 129 DC-8-61 – 198
Tons per aircraft	Blank
Load factor	0.50
DOC without depreciation ($/n. mi.)	Subtract depreciation from total $/n. mi.
IOC ($/n. mi.)	IOC = 0.42 GR[a] GR/n. mi. = seats x LF[b] x yield/n. mi.
Yield ($/passenger n. mi.)	$0.062 at 850 n. mi. (fig. 3)
Depreciation period	5 years for series 50 airplanes 5 and 10 years for model 61 airplanes
Depreciation residual	Zero
Total cost	TC_E[c] = 5/12 x C_t (total airplane price including spares) TC_M[c] = TC_E + $655 000 (add cost of retrofit and spares)

[a]GR – Gross revenue.

[b]LF – Load factor.

[c]TC_E – The depreciated value of the existing airplane at the end of its 7th year, using straight line depreciation. This simulates the condition of dealing with the last 5 years of the airplane's life; with modification (M) vs without modification (E). For the model 61 with a 10-year modification-depreciation period, TC_E is $10/12C_t$, to represent the depreciated value of the existing airplane at the end of its 2nd year, and to simulate the condition of dealing with the last 10 years of the airplane's life.

TABLE VI. – TYPICAL OUTPUT OF THE ROI PROGRAM

FOR PROPOSED DC-8-55 PURCHASE BY NAS 1 7130

ASSUMPTIONS
****

BLOCK DISTANCE	850.	DAILY UTILIZATION	10.4
BLOCK VELOCITY	402.	OPERATING FACTOR	365.
NUMBER OF AIRCRAFT	1.	LOAD FACTOR	0.50
SEATS	135.	TONS	0.
DEPRECIATION PERIOD	5	DEPRECIATION RESIDUAL	0.0
TOTAL COST	3590000.	CAPITALIZATION RATE	0.10
DIRECT OPERATING COST/MILE	1.520	INDIRECT OPERATING COSTS/MILE	1.760
YIELD/MILE	0.062	TAX RATE	0.48
ORDER DATE	0	DELIVERY DATE	1972

FINANCIAL ASSUMPTIONS
****

AMOUNT FINANCED		0.0
PERIOD OF LOAN		12.00
RATE OF INTEREST		0.060
PAYMENT SCHEDULE-		
PAYMENT 1	0.0	
PAYMENT 2	0.0	
PAYMENT 3	0.0	
PAYMENT 4	0.0	

CASH FLOW SUMMARY
MILLIONS OF DOLLARS

	1972	1973	1974	1975	1976	0	0	0	0	0	0	0
	****	****	****	****	****	****	****	****	****	****	****	****
REVENUE	6.386	6.386	6.386	6.386	6.386	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CASH COSTS	5.005	5.005	5.005	5.005	5.005	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DEPRECIATION	0.718	0.718	0.718	0.718	0.718	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INTEREST CHARGES	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
START-UP COSTS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	------	------	------	------	------	------	------	------	------	------	------	------
PRE-TAX PROFIT	0.663	0.663	0.663	0.663	0.663	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INCOME TAXES	0.318	0.318	0.318	0.318	0.318	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TAX CREDITS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	------	------	------	------	------	------	------	------	------	------	------	------
POST TAX PROFIT	0.345	0.345	0.345	0.345	0.345	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL CASH FLOW	1.063	1.063	1.063	1.063	1.063	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CUMULATIVE CASH FLOW	1.063	2.126	3.188	4.251	5.314	0.0	0.0	0.0	0.0	0.0	0.0	0.0

RETURN ON AVERAGE INVESTMENT OVER THE ECONOMIC LIFE OF THE INVESTMENT IS 0.1799

TABLE VII. – CHANGES IN DIRECT OPERATING COSTS
(DC-8 MODELS AT 850 N. MI. RANGE)
(COMPONENTS AS PERCENTAGE OF TOTAL TRIP COST)

Model	55	61	61
Depreciation period for modification, years	5	5	10
Crew	0.0	0.0	0.0
Insurance	0.34	0.33	0.33
Fuel	–0.47	–0.44	–0.43
Maintenance.	0.13	0.12	0.12
Depreciation.	4.31	3.97	1.98
Net change	4.31	3.98	2.00

TABLE VIII. – ECONOMIC EFFECTS OF NACELLE RETROFIT

(a) DC-8-51 (Average service, 5-year depreciation of modification)

Criteria	Per airplane			
	Existing ($ thous)	Modified ($ thous)	Difference	
			($ thous)	(percent)
1. Annual cash flow summary:				
Operating revenue	5910	5910	none	none
Operating expenses less depreciation	4735	4735	none	none
Depreciation	617	748	131	21.2
Profit before taxes	558	427	–131	–23.5
Income taxes	268	205	–63	–23.5
Profit after taxes	290	222	–68	–23.5
Net cash flow	907	970	63	6.9
2. Airplane investment:				
Depreciated book value of the airplane at end of 7th year	3085	3740	655	21.2
	Existing (percent)	Modified (percent)	Difference (percentage points)	
3. Return on airplane investment:				
Discounted cash flow rate of return on airplane investment over the 5-year economic life of the investment	17.62	11.28	–6.34	

TABLE VIII.– ECONOMIC EFFECTS OF NACELLE RETROFIT – Continued

(b) DC-8-52 (Average service, 5-year depreciation of modification)

Criteria	Per airplane			
	Existing ($ thous)	Modified ($ thous)	Difference ($ thous)	Difference (percent)
1. Annual cash flow summary:				
Operating revenue	5837	5837	none	none
Operating expenses less depreciation	4738	4738	none	none
Depreciation	626	757	131	20.9
Profit before taxes	473	342	–131	–27.7
Income taxes	227	164	–63	–27.7
Profit after taxes	246	178	–68	–27.7
Net cash flow	872	935	63	7.2
2. Airplane investment:				
Depreciated book value of the airplane at end of 7th year	3130	3785	655	20.9
	Existing (percent)	Modified (percent)	Difference (percentage points)	
3. Return on airplane investment:				
Discounted cash flow rate of return on airplane investment over the 5-year economic life of the investment	14.83	8.99	–5.84	

TABLE VIII.– ECONOMIC EFFECTS OF NACELLE RETROFIT – Continued

(c) DC-8-53 (Average service, 5-year depreciation of modification)

Criteria	Per airplane			
	Existing ($ thous)	Modified ($ thous)	Difference	
			($ thous)	(percent)
1. Annual cash flow summary:				
Operating revenue	6133	6133	none	none
Operating expenses less depreciation	4907	4907	none	none
Depreciation	672	803	131	19.5
Profit before taxes	554	423	–131	–23.6
Income taxes	266	203	–63	–23.6
Profit after taxes	288	220	–68	–23.6
Net cash flow	960	1023	63	6.6
2. Airplane investment:				
Depreciated book value of the airplane at end of 7th year	3360	4015	655	19.5
	Existing (percent)	Modified (percent)	Difference (percentage points)	
3. Return on airplane investment:				
Discounted cash flow rate of return on airplane investment over the 5-year economic life of the investment	16.10	10.42	–5.68	

TABLE VIII.– ECONOMIC EFFECTS OF NACELLE RETROFIT – Continued

(d) DC-8-54 (Average service, 5-year depreciation of modification)

Criteria	Per airplane			
	Existing ($ thous)	Modified ($ thous)	Difference ($ thous)	Difference (percent)
1. Annual cash flow summary:				
Operating revenue	6402	6402	none	none
Operating expenses less depreciation	4987	4987	none	none
Depreciation	718	849	131	18.2
Profit before taxes	697	566	–313	–18.8
Income taxes	335	272	–63	–18.8
Profit after taxes	362	294	–68	–18.8
Net cash flow	1080	1143	63	5.8
2. Airplane investment:				
Depreciated book value of the airplane at end of 7th year	3590	4245	655	18.2
	Existing (percent)	Modified (percent)	Difference (percentage points)	
3. Return on airplane investment:				
Discounted cash flow rate of return on airplane investment over the 5-year economic life of the investment	18.88	13.12	–5.76	

TABLE VIII. – ECONOMIC EFFECTS OF NACELLE RETROFIT – Continued

(e) DC-8-55 (Average service, 5-year depreciation of modification)

Criteria	Per airplane: Existing ($ thous)	Per airplane: Modified ($ thous)	Per airplane: Difference ($ thous)	Per airplane: Difference (percent)
1. Annual cash flow summary:				
Operating revenue	6386	6386	none	none
Operating expenses less depreciation	5005	5005	none	none
Depreciation	718	849	131	18.2
Profit before taxes	663	532	–131	–19.8
Income taxes	318	255	–63	–19.8
Profit after taxes	345	277	–68	–19.8
Net cash flow	1063	1126	63	5.9
2. Airplane investment:				
Depreciated book value of the airplane at end of 7th year	3590	4245	655	18.2
	Existing (percent)	Modified (percent)	Difference (percentage points)	
3. Return on airplane investment:				
Discounted cash flow rate of return on airplane investment over the 5-year economic life of the investment	17.99	12.36	–5.63	

TABLE VIII.– ECONOMIC EFFECTS OF NACELLE RETROFIT – Continued

(f) DC-8-61 (Average service, 5-year depreciation of modification)

Criteria	Per airplane			
	Existing ($ thous)	Modified ($ thous)	Difference	
			($ thous)	(percent)
1. Annual cash flow summary:				
Operating revenue	9390	9390	none	none
Operating expenses less depreciation	6272	6272	none	none
Depreciation	773	904	131	16.9
Profit before taxes	2345	2214	–131	–5.6
Income taxes	1126	1063	–63	–5.6
Profit after taxes	1219	1151	–68	–5.6
Net cash flow	1992	2055	63	3.2
2. Airplane investment:				
Depreciated book value of the airplane at end of 7th year	3865	4520	655	16.9
	Existing (percent)	Modified (percent)	Difference (percentage points)	
3. Return on airplane investment:				
Discounted cash flow rate of return on airplane investment over the 5-year economic life of the investment	57.36	46.35	–11.01	

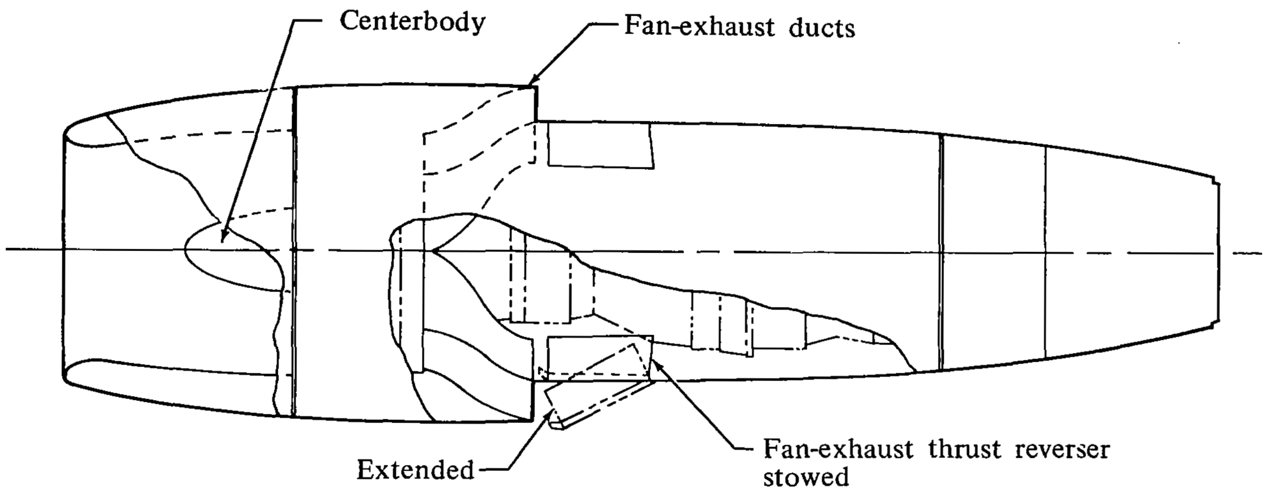
TABLE VIII.– ECONOMIC EFFECTS OF NACELLE RETROFIT – Concluded

(g) DC-8-61 (Average service, 10-year depreciation of modification)

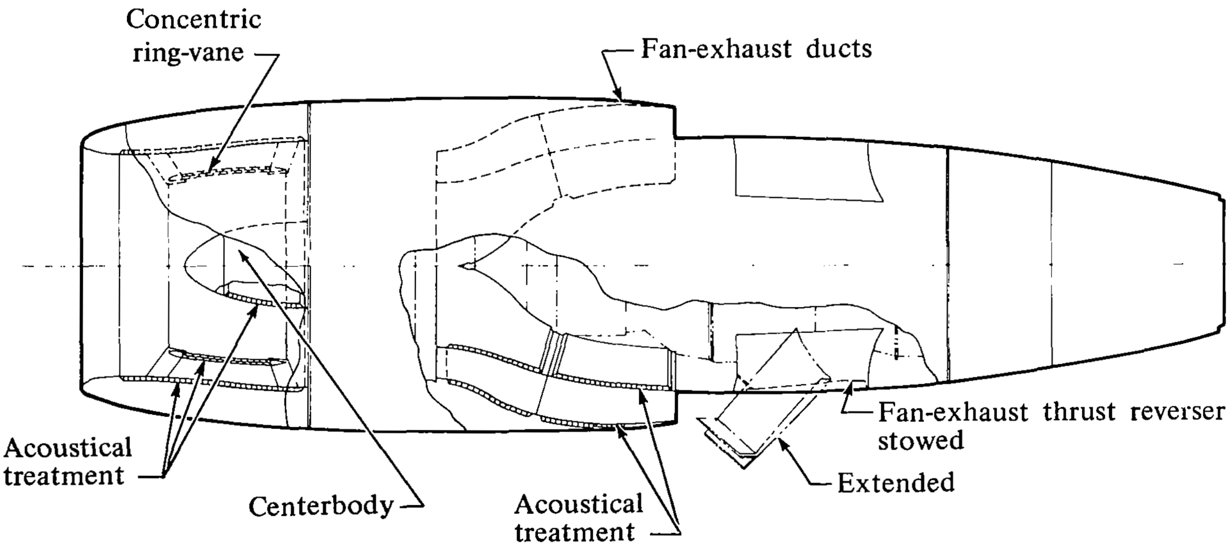
Criteria	Per airplane			
	Existing ($ thous)	Modified ($ thous)	Difference ($ thous)	Difference (percent)
1. Annual cash flow summary:				
Operating revenue	9390	9390	none	none
Operating expenses less depreciation	6272	6272	none	none
Depreciation	773	838	65	8.4
Profit before taxes	2345	2280	–65	–2.8
Income taxes	1126	1094	–32	–2.8
Profit after taxes	1219	1186	–33	–2.8
Net cash flow	1992	2024	32	1.6
2. Airplane investment:				
Depreciated book value of the airplane at end of 2nd year	7730	8385	655	8.5
	Existing (percent)	Modified (percent)	Difference (percentage points)	
3. Return on airplane investment:				
Discounted cash flow rate of return on airplane investment over the 10-year economic life of the investment	25.80	23.36	–2.44	

TABLE IX. – FIVE-YEAR ECONOMIC IMPACT ON OPERATIONS OF TOTAL FLEET RETROFIT

Estimated 1972 fleet		Change in profit after taxes		Change in investment		Change in return on airplane investment	
DC-8 model	No. in fleet	$ million	Percent of existing	$ million	Percent of existing	Percentage points	Percent of existing
51	34	–11.6	–23.5	22.3	21.2	–6.3	–36.0
52	27	–9.2	–27.7	17.7	20.9	–5.8	–39.4
53	27	–9.2	–23.6	17.7	19.5	–5.7	–35.3
54	28	–9.5	–18.8	18.3	18.2	–5.8	–30.5
55	33	–11.2	–19.8	21.6	18.2	–5.6	–31.3
61	101	–34.3	–5.6	66.2	16.9	–11.0	–19.2
Total	250	–85.0	–	163.8	–	–	–
Average	–	–	–10.2	–	18.5	–8.1	–23.5



(a) Existing nacelle.



(b) Modified (retrofit) nacelle.

Figure 1. – Plan view of existing and modified (retrofit) nacelle design.

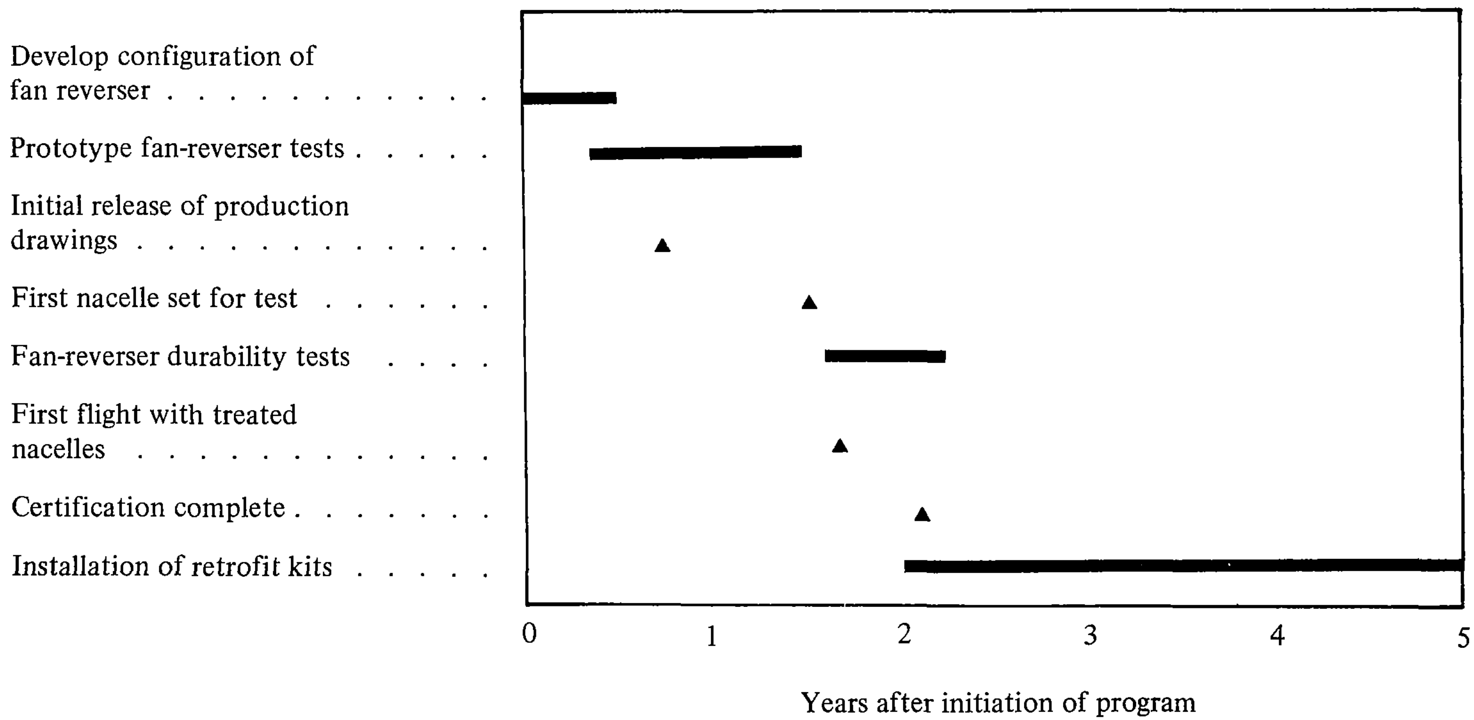


Figure 2. – Assumed retrofit program schedule.

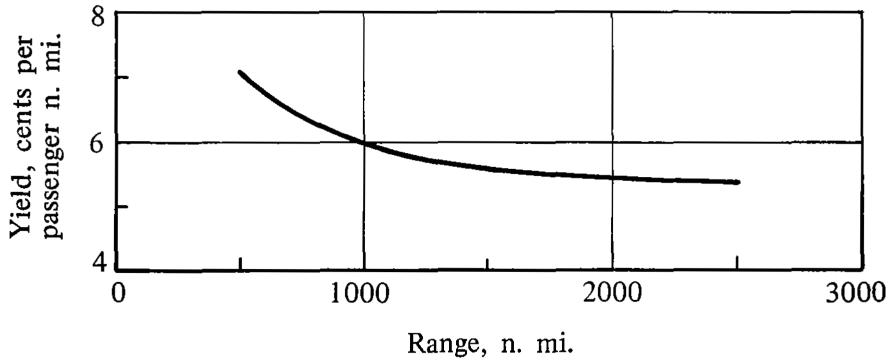
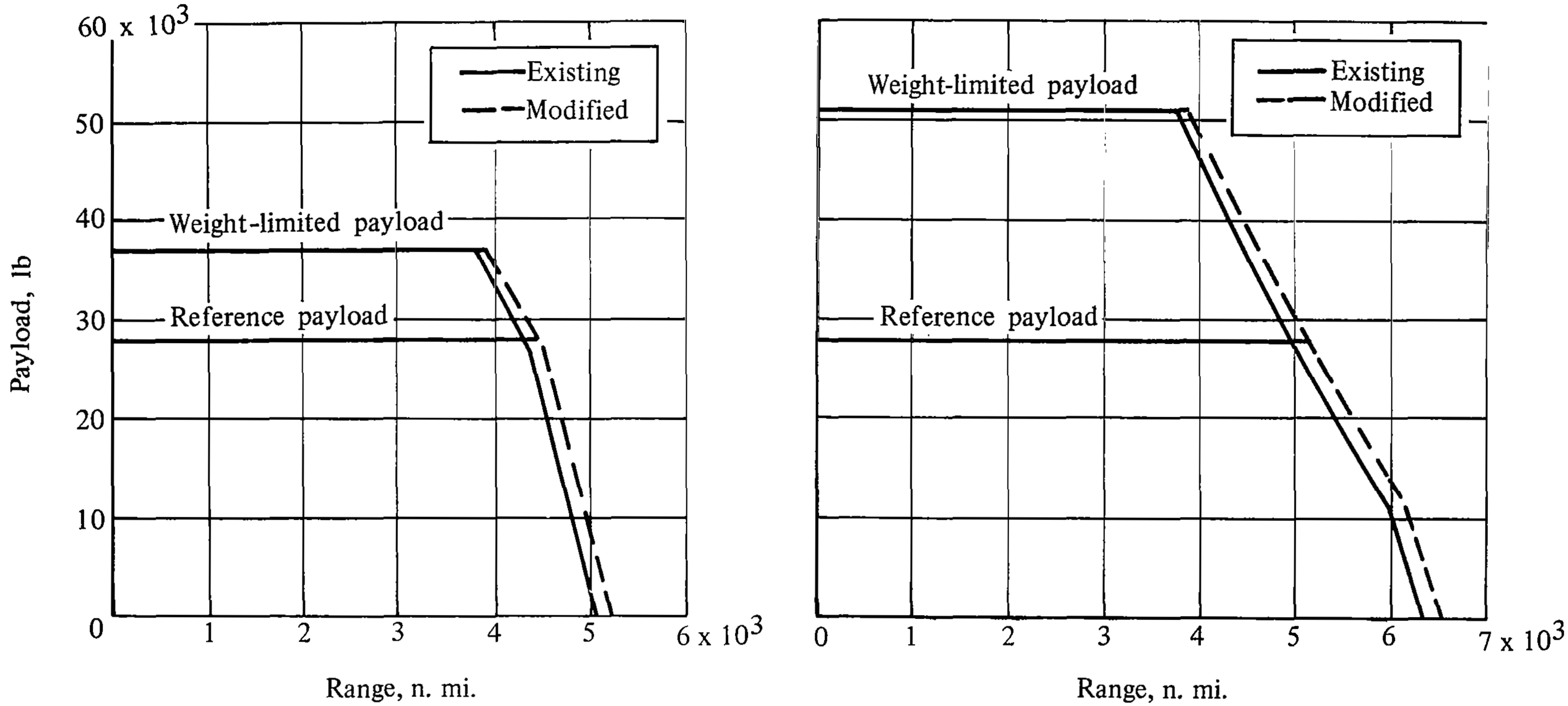


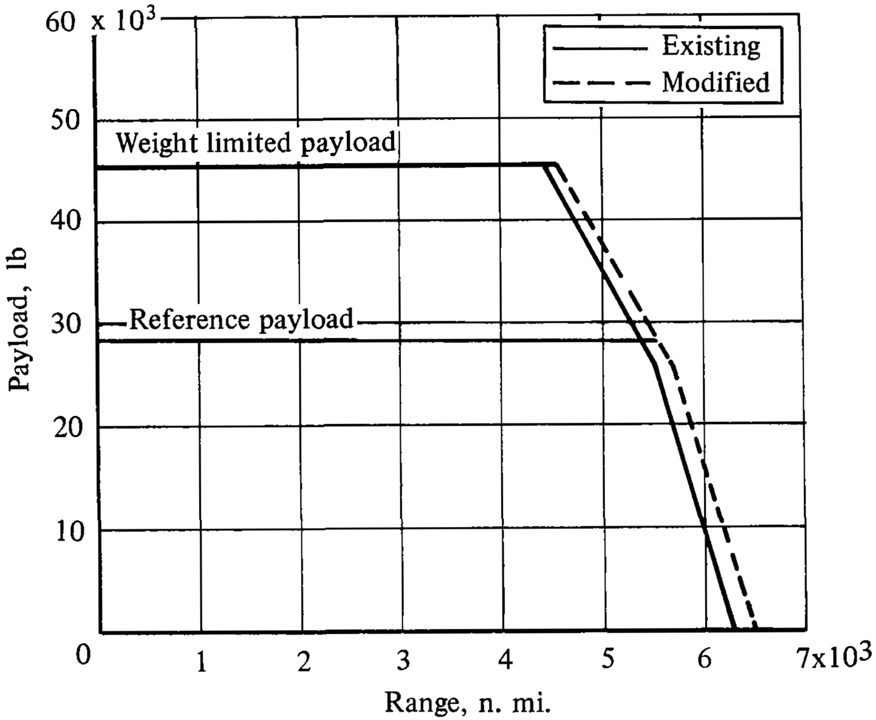
Figure 3. – Yield vs range, U.S. domestic service.



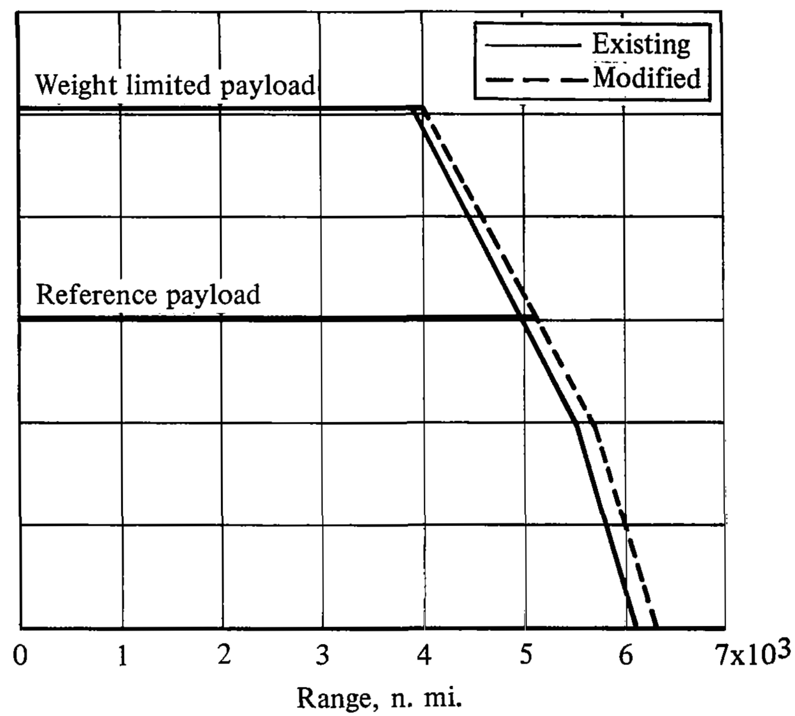
(a) Model DC-8-51

(b) Model DC-8-52

Figure 4. – Payload-range characteristics, domestic rules, standard day.

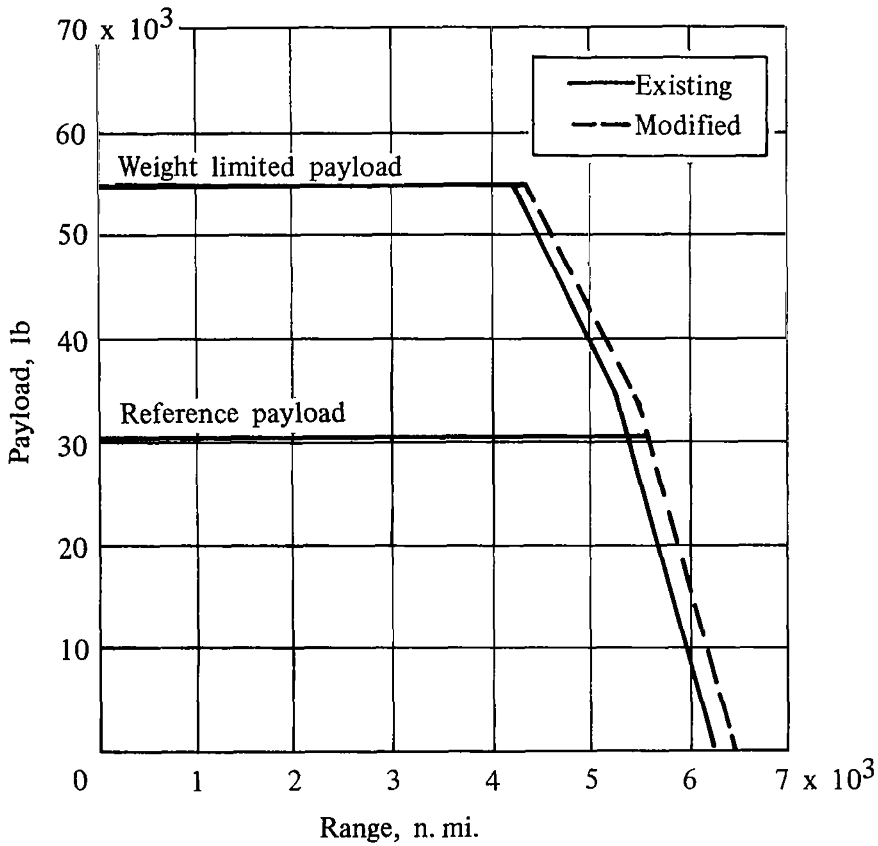


(c) Model DC-8-53.

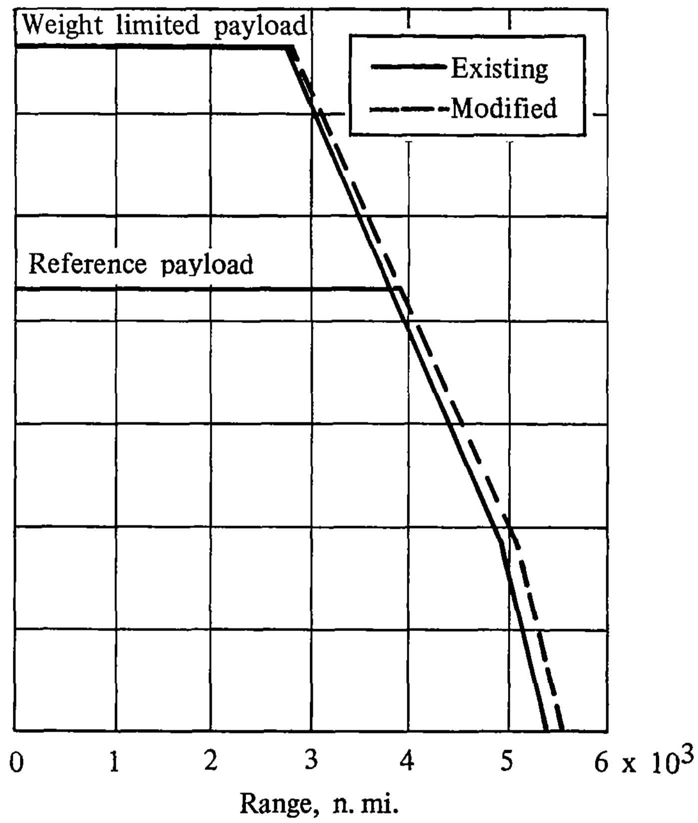


(d) Model DC-8-54.

Figure 4. – Continued.

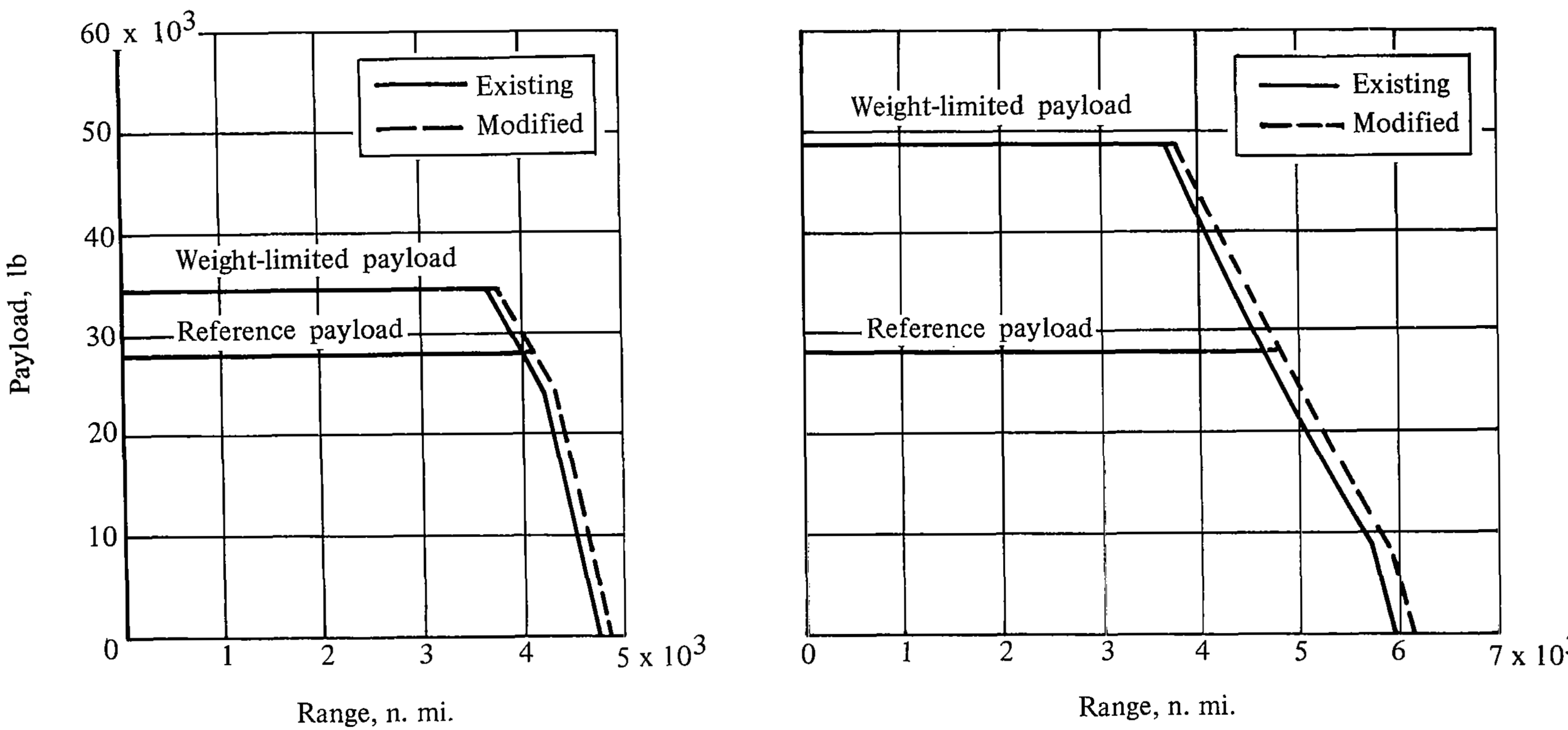


(e) Model DC-8-55



(f) Model DC-8-61

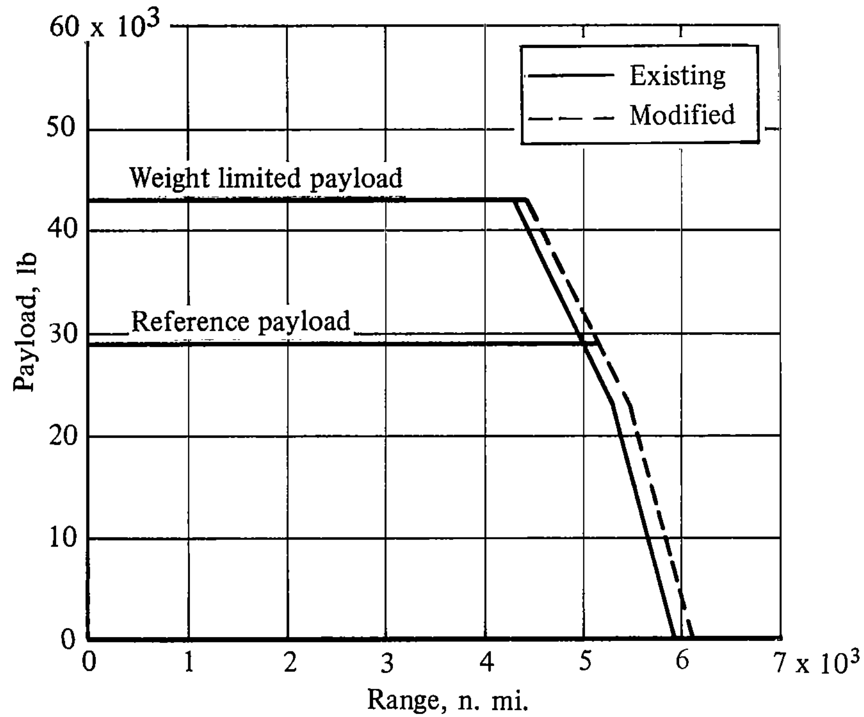
Figure 4. – Concluded.



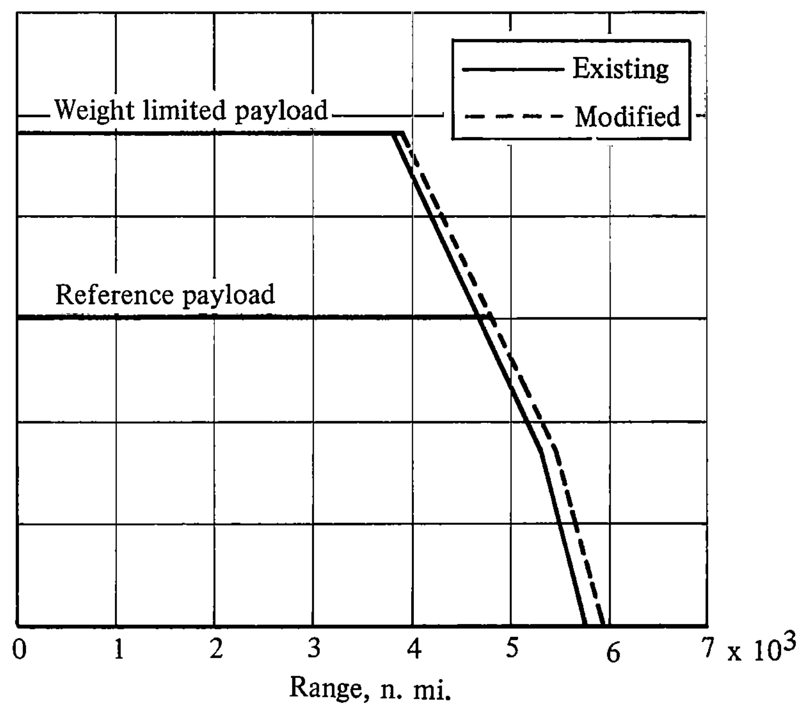
(a) Model DC-8-51

(b) Model DC-8-52

Figure 5. – Payload-range characteristics, international rules, standard day.

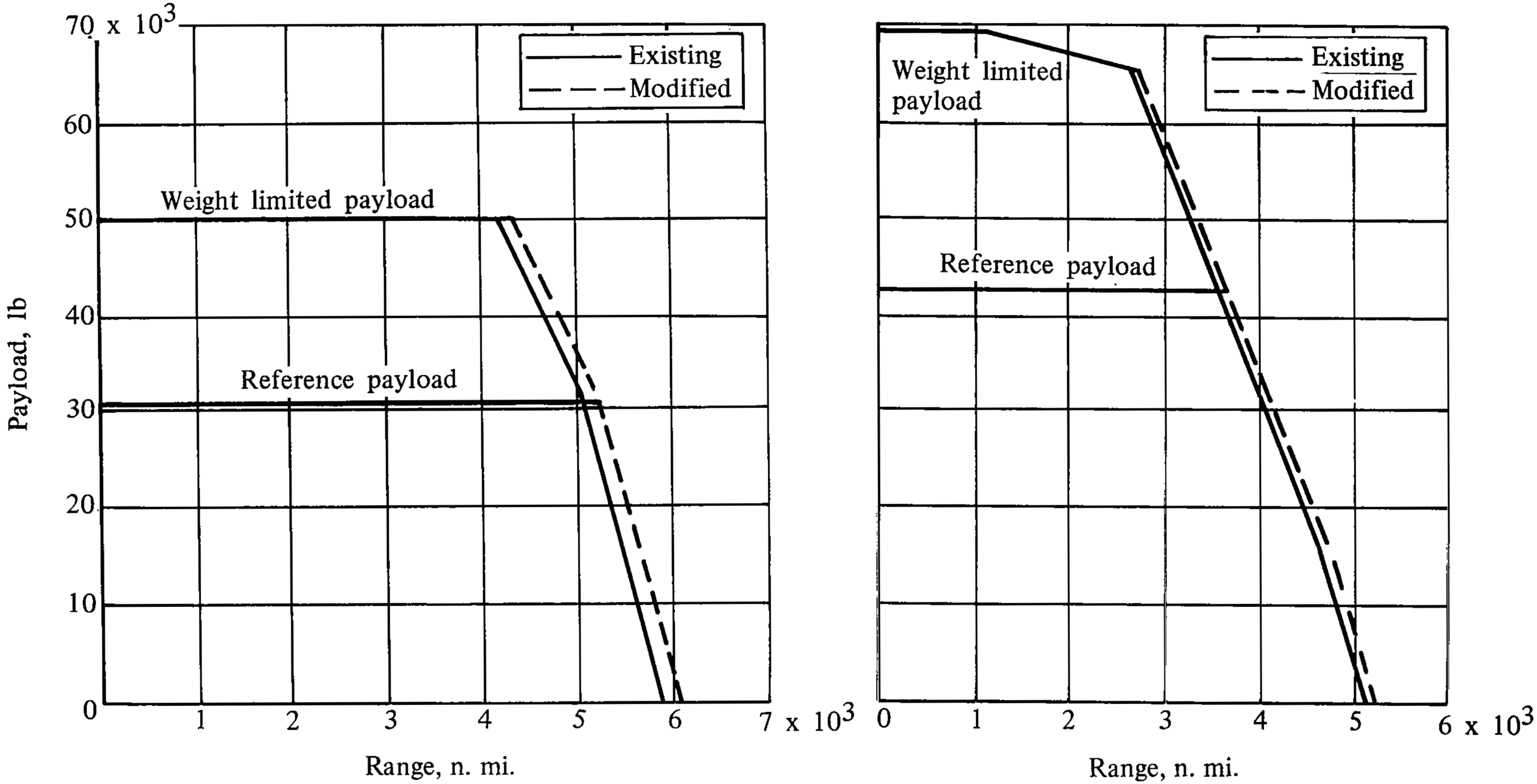


(c) Model DC-8-53.



(d) Model DC-8-54.

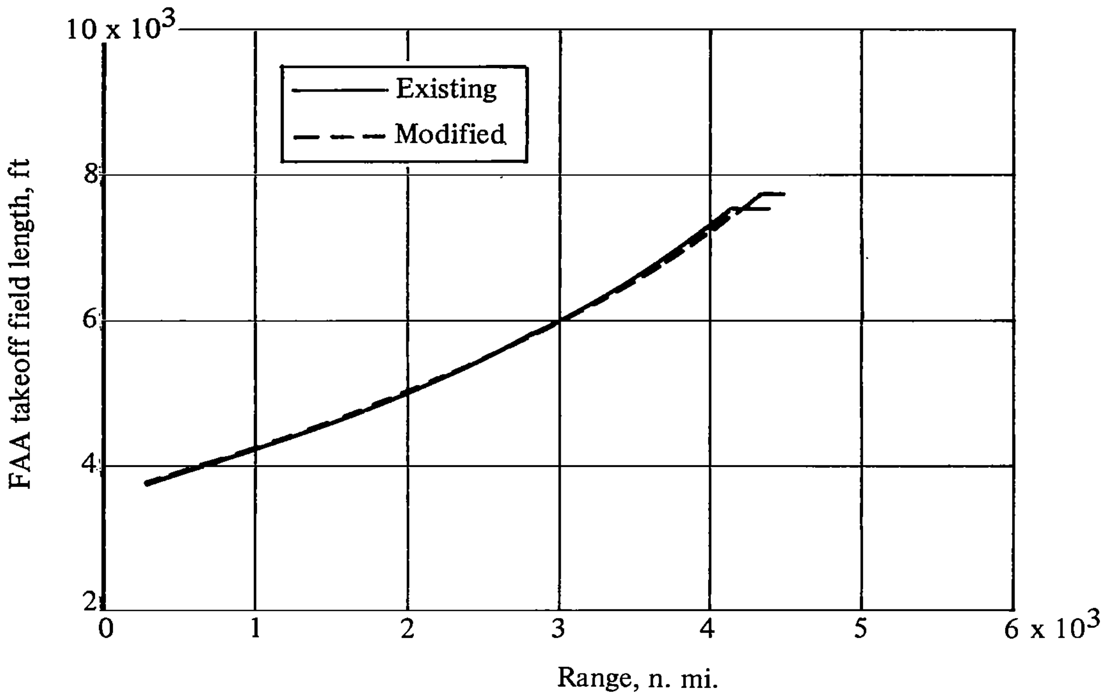
Figure 5 – Continued.



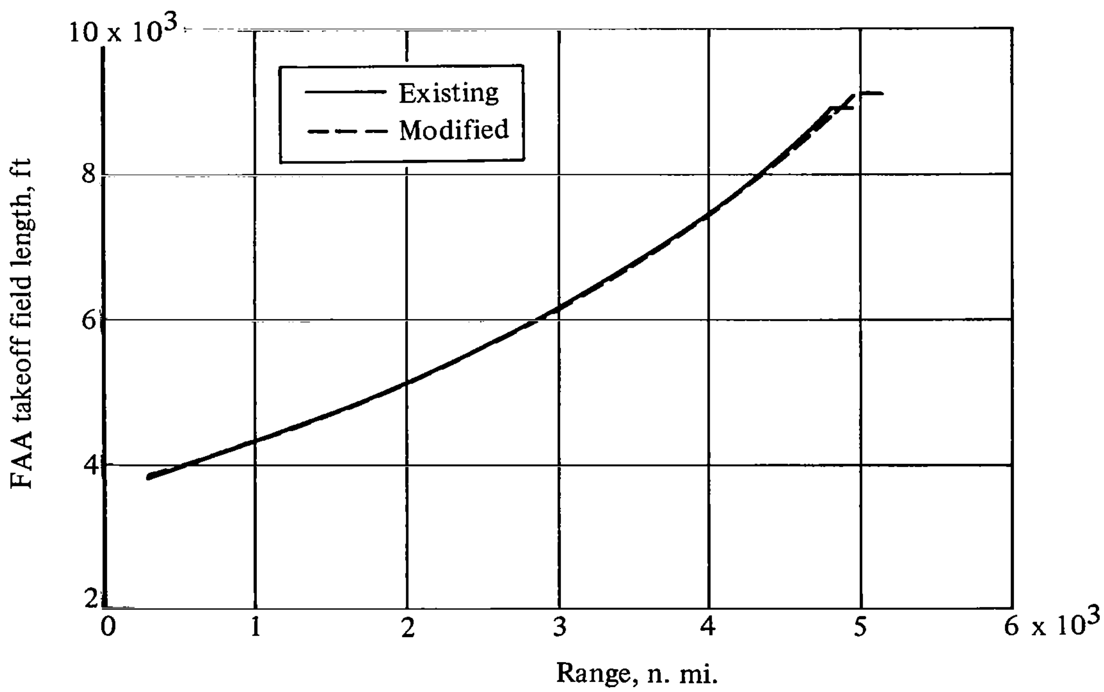
(e) Model DC-8-55

(f) Model DC-8-61

Figure 5. – Concluded.

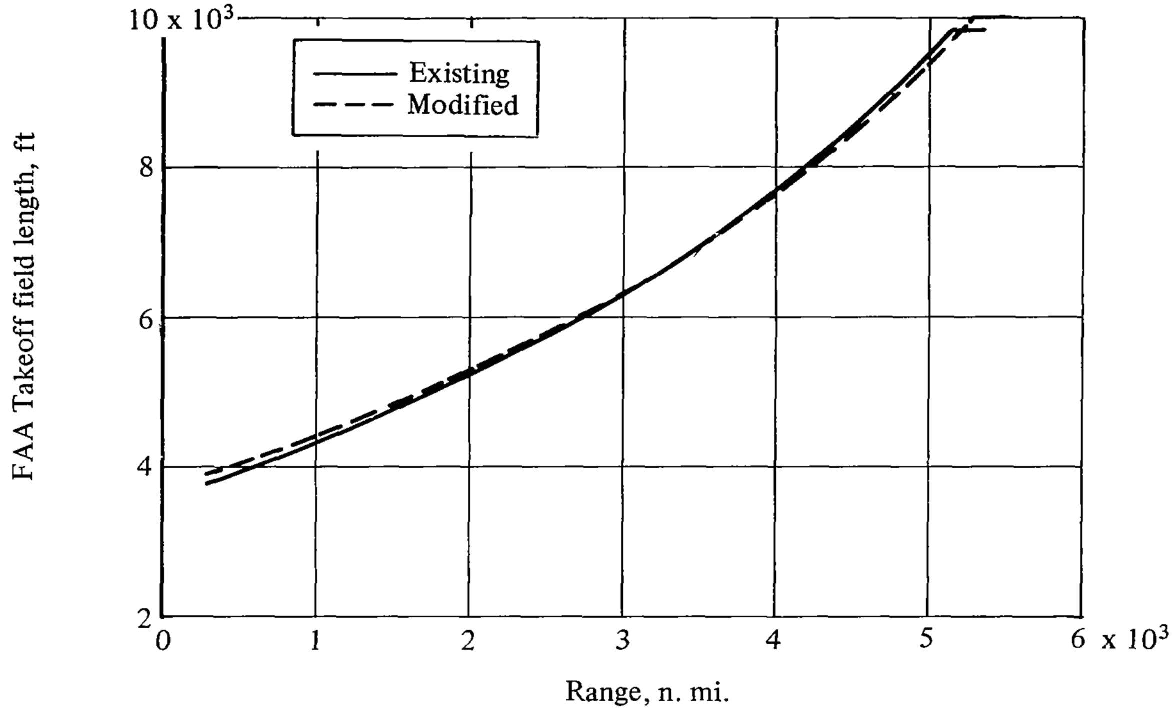


(a) Model DC-8-51

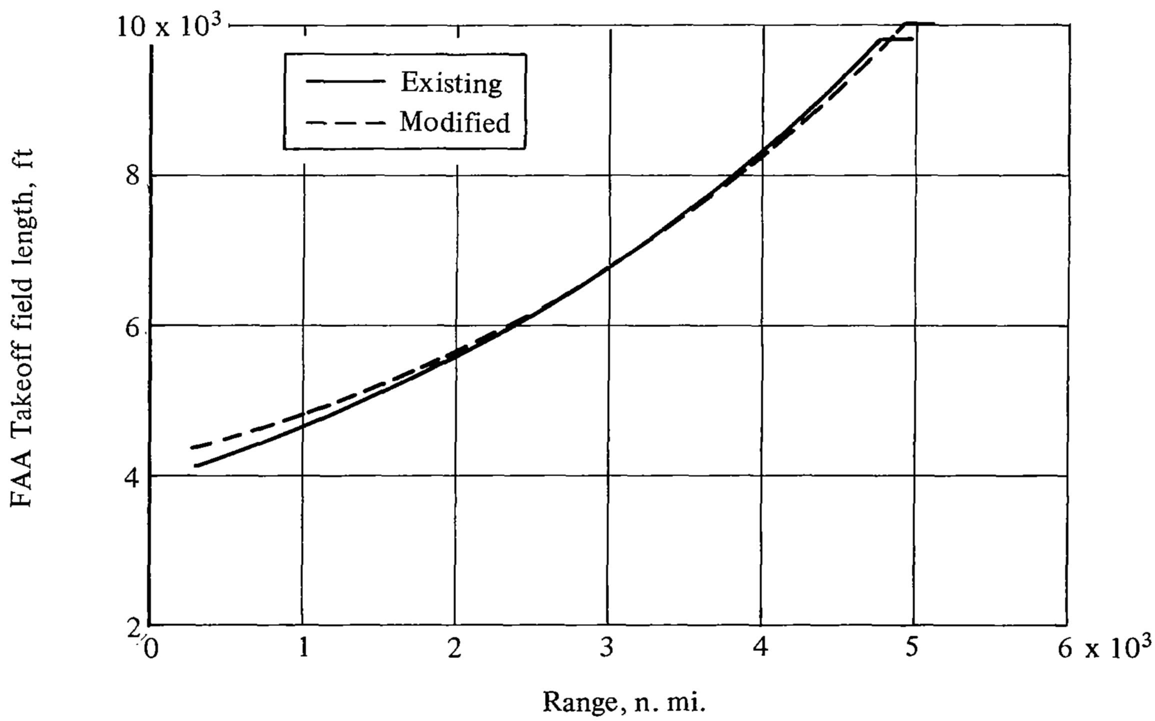


(b) Model DC-8-52

Figure 6. – FAA Takeoff field length vs range, for reference payload. Takeoff field length based on sea level, 84°F, 25-degree flaps. Range based on standard atmospheric conditions. Domestic rules.

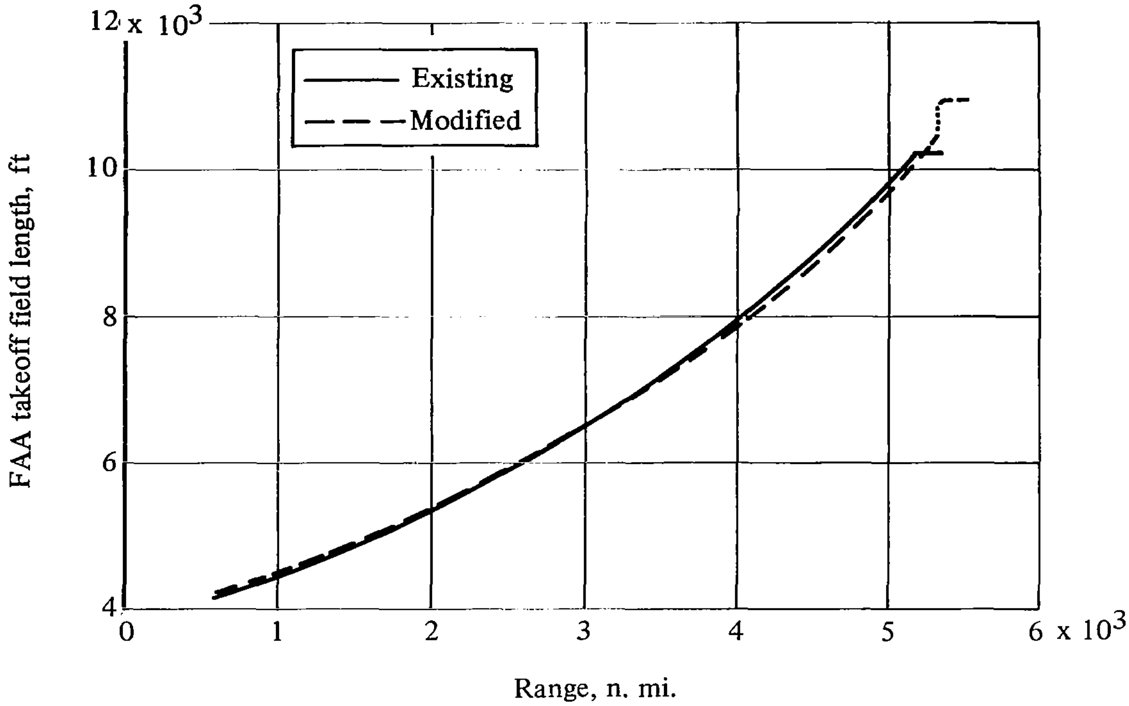


(c) Model DC-8-53

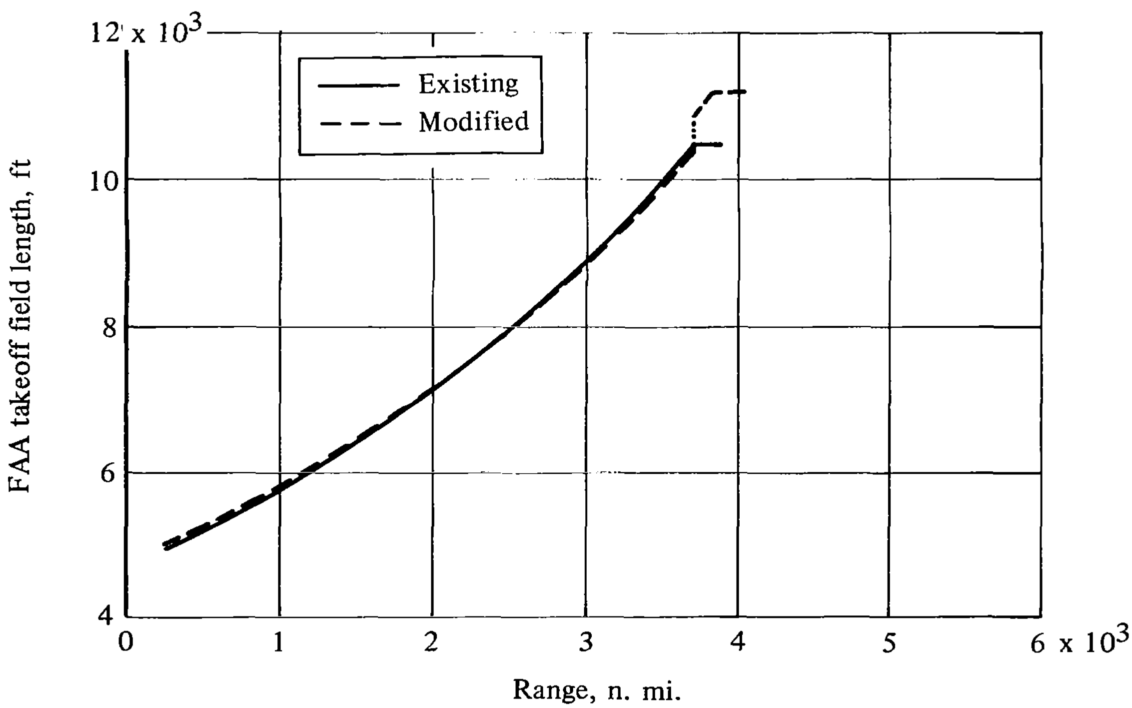


(d) Model DC-8-54

Figure 6. – Continued.



(e) DC-8-55



(f) DC-8-61

Figure 6. – Concluded.

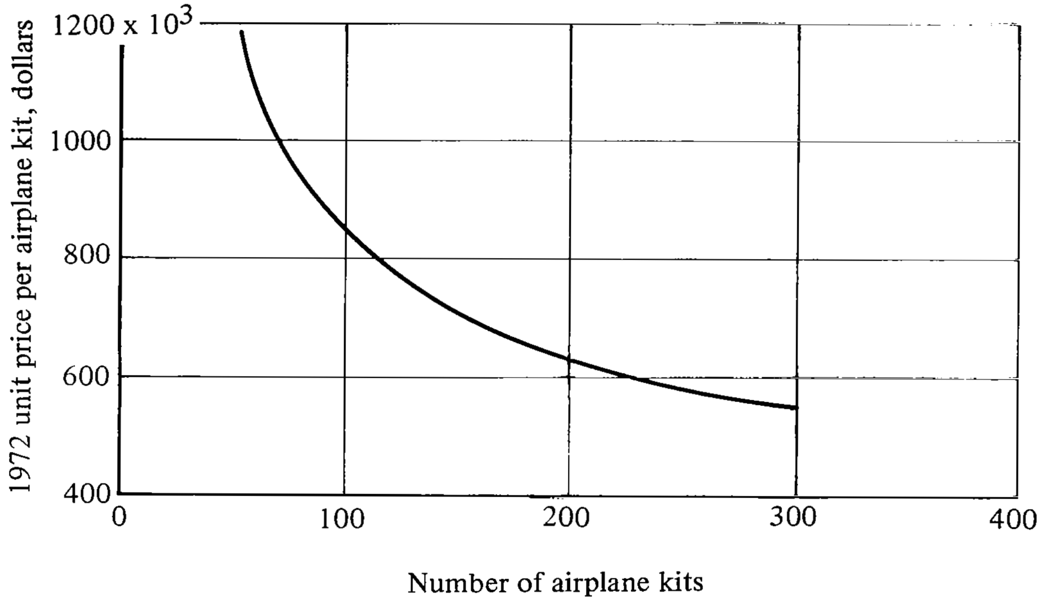
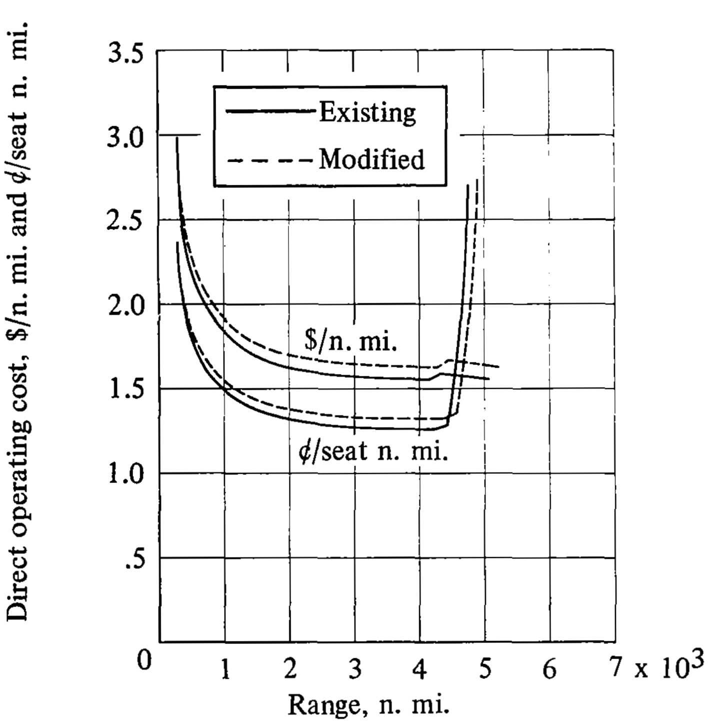
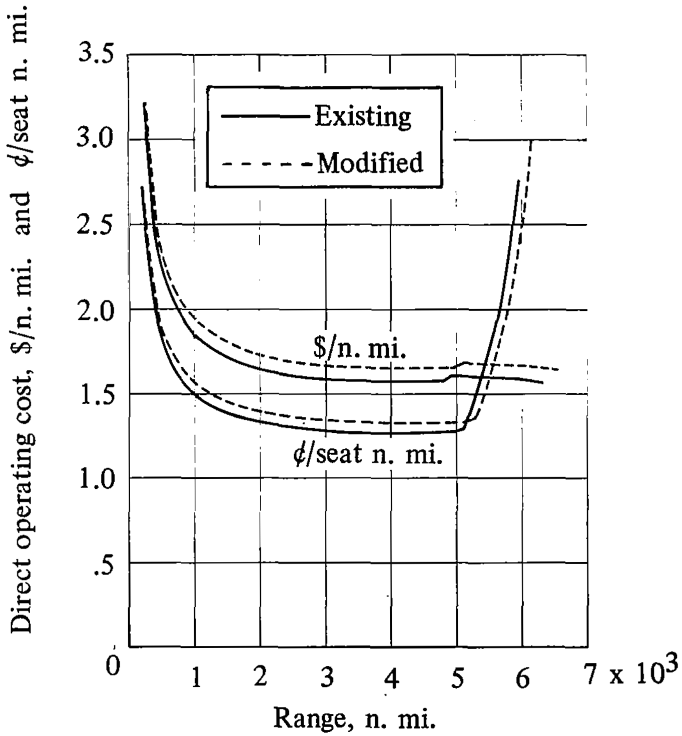


Figure 7. – Variation of retrofit kit price with quantity.

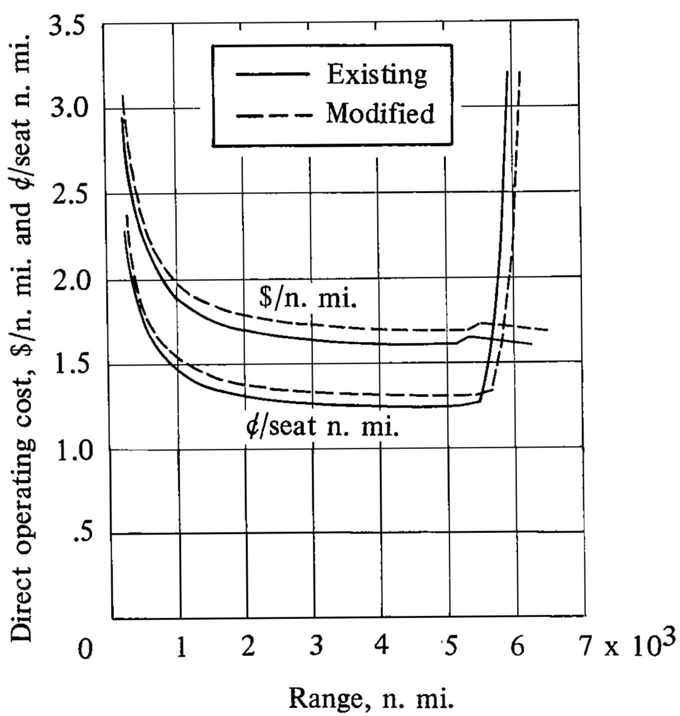


(a) Model DC-8-51

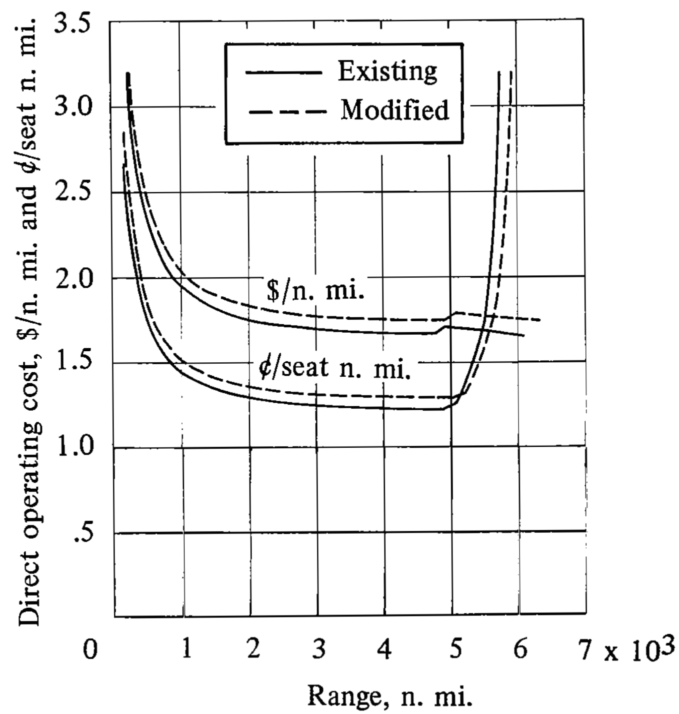


(b) Model DC-8-52

Figure 8. – Direct operating cost, domestic rules, 5-year depreciation on modifications, standard day.

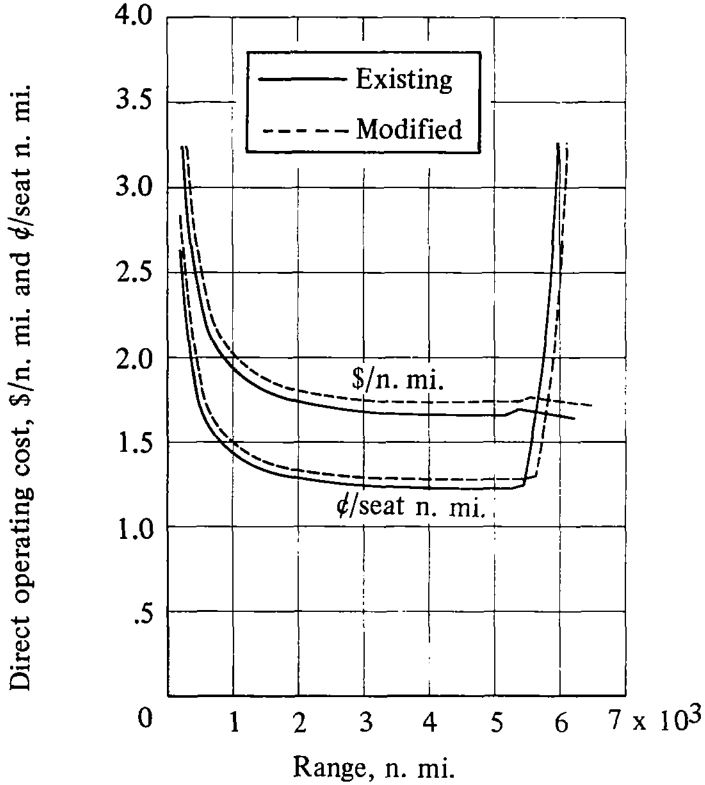


(c) Model DC-8-53

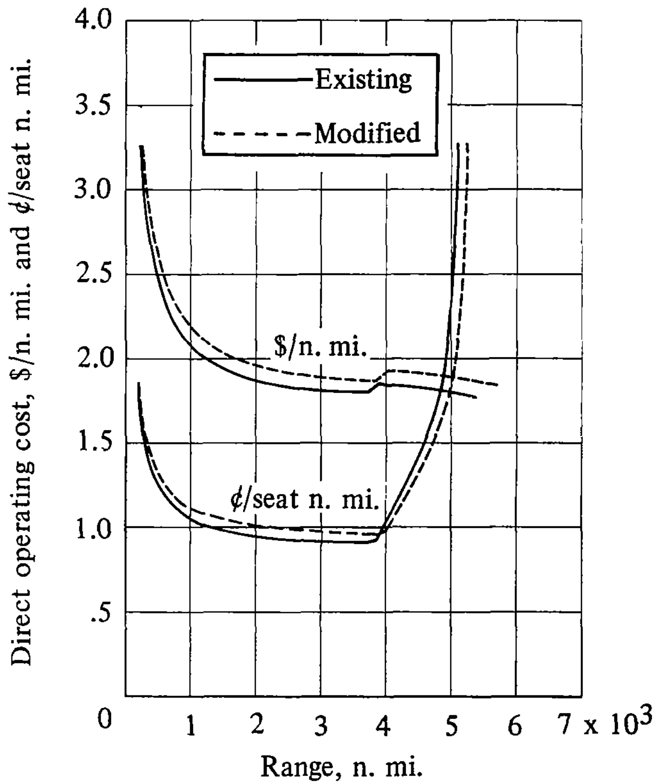


(d) Model DC-8-54

Figure 8. - Continued.

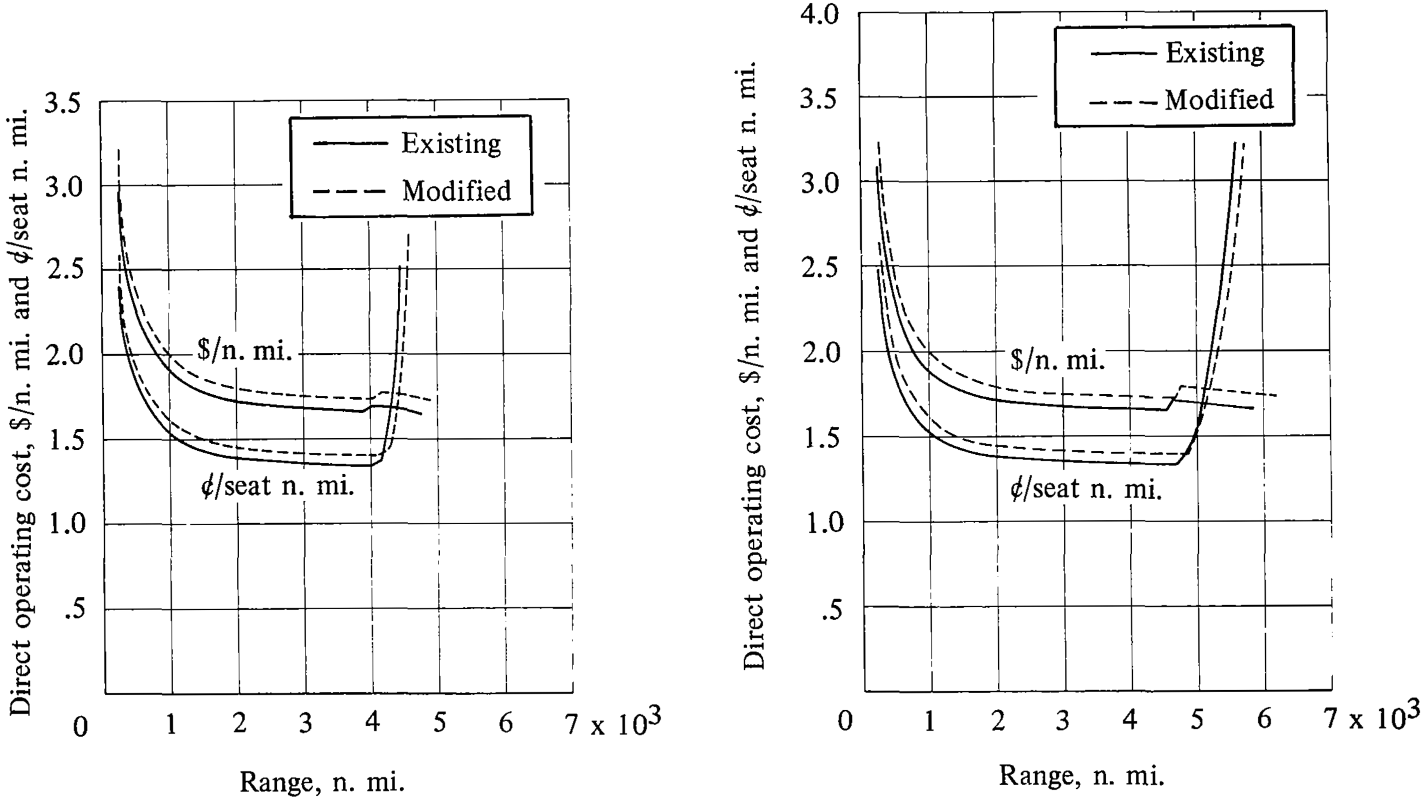


(e) Model DC-8-55



(f) Model DC-8-61

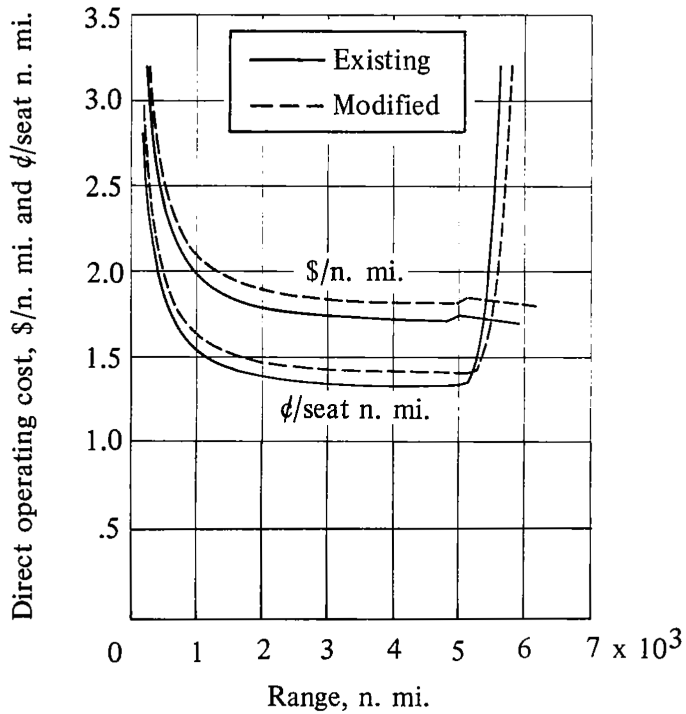
Figure 8. – Concluded.



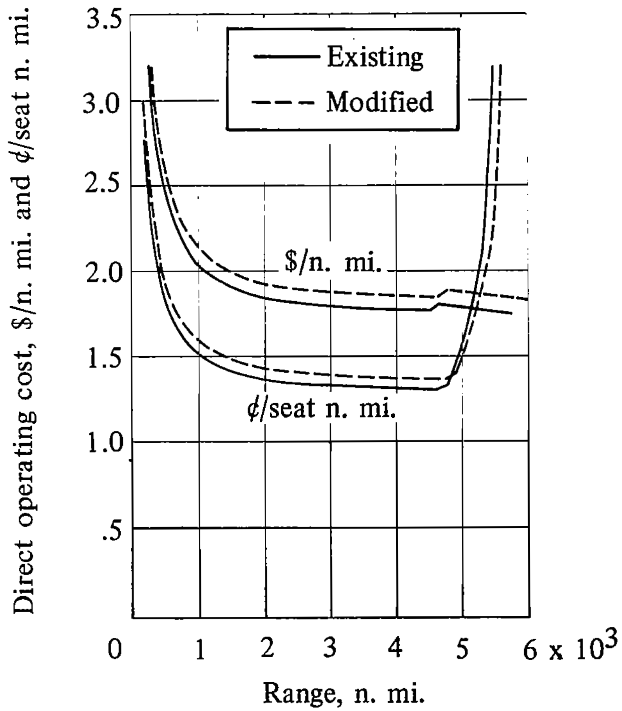
(a) Model DC-8-51

(b) Model DC-8-52

Figure 9. – Direct operating cost, international rules, 5-year depreciation on modifications, standard day.

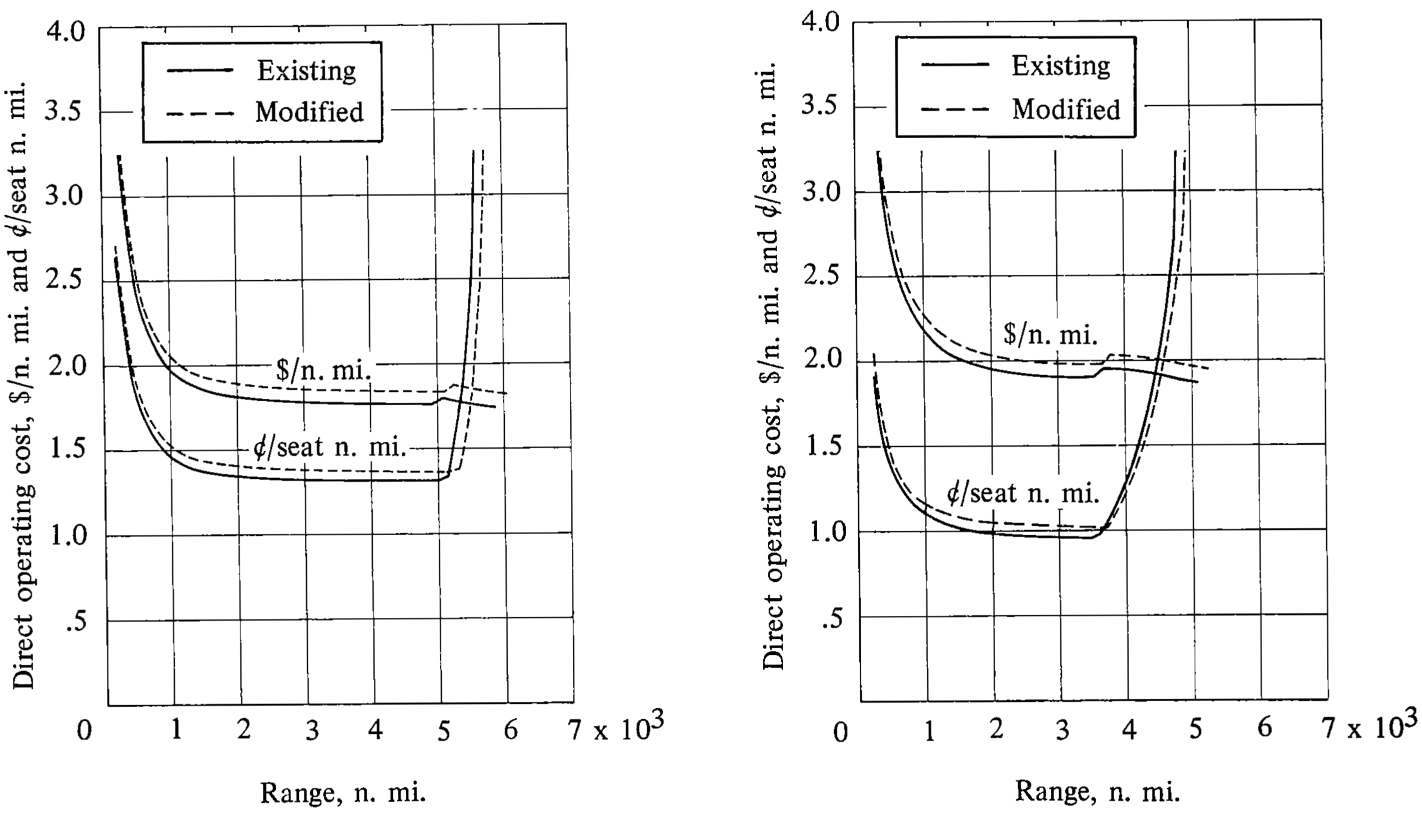


(c) Model DC-8-53



(d) Model DC-8-54

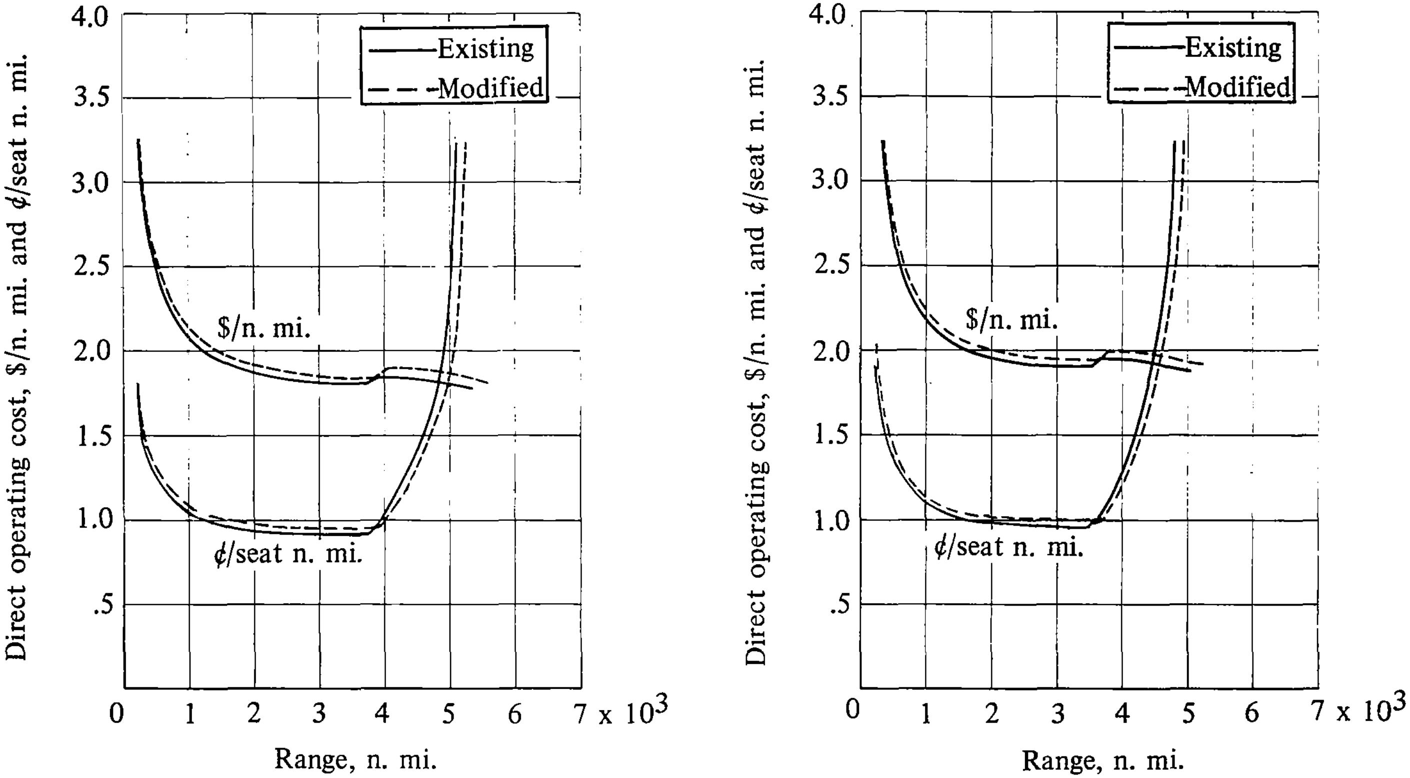
Figure 9. – Continued.



(e) Model DC-8-55

(f) Model DC-8-61

Figure 9. – Concluded.



(a) Domestic rules

(b) International rules

Figure 10. – Direct operating cost, DC-8-61, with 10-year depreciation on modifications, standard day.

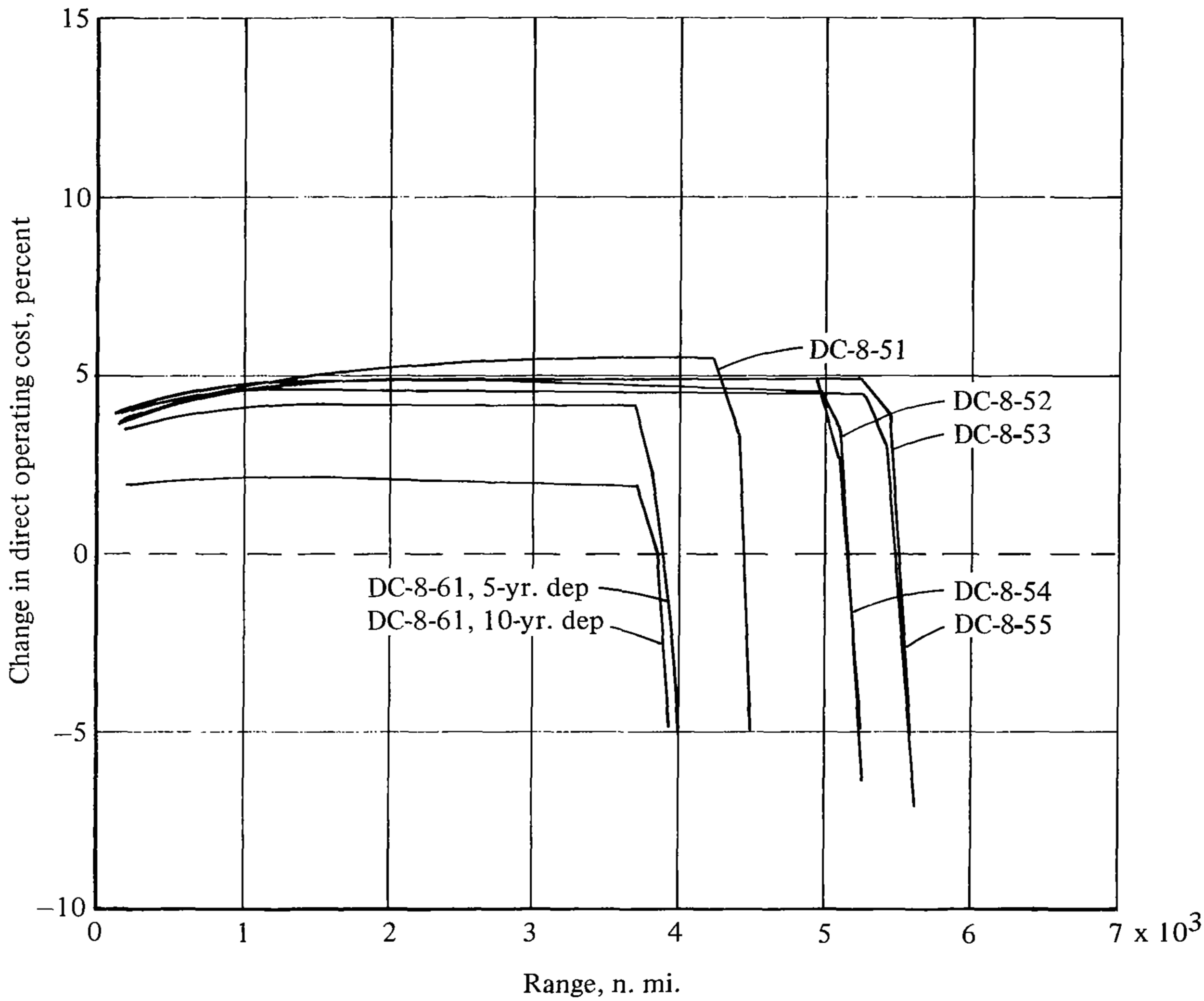


Figure 11. – Change in direct operating cost resulting from retrofit, 5-year depreciation on modifications of all series 50 airplanes, 5 and 10-year depreciation on modifications of model 61. Domestic operating rules.

NASA-Langley, 1970 —— 2 CR-1709